EFFECT OF TYPE OF STIMULI ON

THE BENEFIT DERIVED FROM ENVELOPE ENHANCEMENT

IN INDIVIDUALS WITH ANSD

Kriti Arora

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A Dissertation Submitted in Part-Fulfillment of Degree of Master of Science
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ALL INDIA INSTITUTE OF SPEECH AND HEARING

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CERTIFICATE

This is to certify that this dissertation entitled **'Effect of Type of Stimuli on the Benefit Derived from Envelope Enhancement in Individuals with ANSD'** is a bonafide work submitted in part-fulfillment for degree of Master of Science (Audiology) of the student with Registration Number: 17AUD024. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
May, 2019

Dr. M. Pushpavathi
Director
All India Institute of Speech and Hearing
Manasagangothri, Mysuru-570006

CERTIFICATE

This is to certify that this dissertation entitled **'Effect of Type of Stimuli on the Benefit Derived from Envelope Enhancement in Individuals with ANSD'** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
May, 2019

Guide
Dr. Sandeep M.
Associate Professor in Audiology
All India Institute of Speech and Hearing
Manasagangothri, Mysuru-570006

DECLARATION

This is to certify that this dissertation entitled **'Effect of Type of Stimuli on the Benefit Derived from Envelope Enhancement in Individuals with ANSD'** is the result of my own study under the guidance of Dr. Sandeep M., Associate Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any Diploma or Degree.

Mysuru **Registration No. 17AUD024**

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INTRODUCTION

A variety of hearing disorders influence the processing of incoming signal at various stations in the auditory system. Auditory neuropathy, currently known as auditory neuropathy spectrum disorder (ANSD) is known to affect the normal synchronous activity in the auditory nerve, while preserving the amplification function of the inner ear (Zeng, Oba, Garde, Sininger, & Starr, 1999).

Poor speech recognition is a hallmark of individuals with ANSD (Zeng, Kong, Michalewski, & Starr, 2005). This can be attributed to the severely impaired temporal processing abilities in these individuals, not commensurate to their hearing thresholds (Kumar & Jayaram, 2011; Narne & Vanaja, 2009b; Zeng et al., 2005). Temporal modulation transfer function has been used to determine the temporal processing abilities in individuals with ANSD and the studies have shown abnormally high modulation detection thresholds which significantly correlate with their speech perception scores in quiet (Kumar & Jayaram, 2011; Rance, McKay, & Grayden, 2004; Zeng et al., 1999, 2005). Individuals with ANSD are reported to display greater difficulty in the perception of consonants, mainly the stops or plosives (Kumar & Jayaram, 2011), owing to short and fast changing acoustic cues in these consonants (Kraus et al., 2000). Zeng et al. (1999) attributed the difficulty in the perception of stop consonants to their impaired perception of fast modulation of speech, which results in the poor perception of burst duration and transition duration that are crucial in the perception of stops. The perception of nasal consonants is also known to be affected in them, attributable to their impaired ability to use low-frequency spectral cues (Narne & Vanaja, 2008).

The auditory management of individuals with ANSD is one of the most difficult conundrums for the audiologists. Conventional amplification devices such as hearing aids are proven to be of limited benefit in improving speech perception in these individuals (Miyamoto, Kirk, Renshaw, & Hussain, 1999; Shallop, Peterson, Facer, Fabry, & Driscoll, 2001). Compared to hearing aids, frequency modulation devices appear to provide greater benefit by improving the signal-to-noise ratio (SNR) of the target speech (Rance, Corben, Du Bourg, King, & Delatycki, 2010). However, these devices are promising in few listening situations only. Although cochlear implant is one of the management options, Miyamoto et al. (1999) reported cochlear implants to benefit only those individuals with ANSD having presynaptic or synaptic lesions. Moreover, the cost and invasive nature associated with cochlear implants entails exploration of other rehabilitative alternatives.

One of the means of improving speech perception is to use clear speech. Zeng and Liu (2006) compared the performance of 13 adults with ANSD in clear and conversational speech styles using speech sentences. A mean improvement of 1.3dB in speech reception thresholds was reported when silent gaps were introduced in conversational speech which actually reduced the rate of speech. Clear speech resulted in a significant improvement of speech perception in both quiet and noisy situations.

In instances where auditory cues are compromised, as in the presence of competing-noise, visual cues are typically used to facilitate speech perception (Macleod & Summerfield, 1987; Tye-Murray, Sommers, & Spehar, 2007). Balan and

Maruthy (2018) assessed the benefit of visual cue supplementation and acoustic enhancement in improving speech perception in individuals with ANSD. The results showed higher speech identification scores in the auditory-visual modality in both quiet and 0dB SNR when compared to the visual-only and auditory-only modalities. However, the acoustic enhancement was shown to have a negligible influence on speech perception. Because the study used consonant-vowel (CV) pairs for testing with utilisation of stop consonants, the authors confined their inferences to the perception of stop consonants.

Hassan (2011) investigated the perception of temporally modified CV pairs in 14 adults with ANSD. It was found that, with lower inter-stimulus intervals between CV pairs (ranging from 409ms to 645ms) and prolongation of transition duration (from 20ms to 250ms), the participants could distinguish the CV pairs better.

The utility of combined spectral and temporal enhancement in improving speech perception in individuals with ANSD has also been documented. Companding is one such method which enhances the spectral contrast by increasing the peak to valley difference in the spectrum (Bhattacharya & Zeng, 2007). Such an algorithm was expected to compensate for the poor frequency resolution in individuals with hearing impairment (Tyler, Fernandes, & Wood, 1980). Narne, Barman, Deepthi, and Shachi (2014) evaluated consonant recognition and sentence perception in noise, with and without companding. Results showed that, across all SNRs, a non-monotonic improvement was seen in consonant identification scores for enhanced stimuli.

There is a faction of literature that shows evidence for usefulness of envelope enhancement of speech in listeners with ANSD. Narne and Vanaja (2008) reported better perception of syllables (CV) in individuals with ANSD, with the digital enhancement of envelope of speech spectrum. Narne and Vanaja (2009b) reported an improvement of about 0% to 36% for envelope enhanced words in 12 individuals with ANSD. On the contrary, Balan and Maruthy (2018) found no significant benefits of envelope enhancement in the speech perception of forty individuals with ANSD. The study had utilized stop consonants in the context of /a/ to assess speech perception.

1.1 Justification for the Study

It is well known that individuals with ANSD have auditory perceptual deficits attributable to the disruption of temporal cues (Kraus et al., 2000; Starr et al., 1991). Excessive forward masking (Kraus et al., 2000; Zeng et al., 2005) and the loss of consonant-vowel distinction (Narne & Vanaja, 2009b) are some of the reasons for difficulty in understanding speech in these individuals. Despite an in-depth understanding of these underlying mechanisms responsible for perceptual deficits, management of ANSD remains one of the most difficult conundrums for audiologists.

Previous investigations have shown two routes for the management of individuals with ANSD: first, by making use of various acoustic enhancement strategies and second, with visual cue supplementation. Although the benefits of using visual cues appear to be promising (Balan & Maruthy, 2018; Maruthy & Geetha, 2011), the numerous difficulties associated with visual communication such as, disruption of communication in a dark room, or with a distant speaker, or challenges in the perception of homophene warrants further exploration of the management through the auditory modality.

The extent of benefits for speech perception derived from various acoustic enhancement strategies is highly variable across different studies. Several studies report acoustic enhancements of speech to significantly improve perception in individuals with ANSD (Hassan, 2011; Kumar & Jayaram, 2011; Narne & Vanaja, 2009a, 2009b; Mathai & Yathiraj, 2013), while Balan and Maruthy, (2018) show negligible improvement in the perception. The existing literature suggests envelope enhancement strategy to be most beneficial in improving speech perception in individuals with ANSD. Narne and Vanaja (2009a) reported a mean improvement of 17.8% in speech identification scores in quiet using envelope enhancement strategy. Also, they reported a 5% improvement in speech identification scores at 0dB SNR in ANSD individuals with good speech identification scores. In another study, they showed that envelope enhancement led to 8% to 36% improvement in speech identification scores in quiet with a mean improvement of 18.3% (Narne & Vanaja, 2012). However, it is important to note that, an improvement of 18.3% signifies that envelope enhancement could improve perception of only four of the twenty-five original stimuli used in the study. Therefore, although the results of the previous investigations show statistically significant improvement in speech perception using envelope enhancement strategy, the benefits are not appreciable. Furthermore, in both of the aforementioned studies, the sample sizes were relatively small, and considering that ANSD is known to be a heterogeneous condition, the findings cannot necessarily be generalised across the clinical population.

On the contrary, Balan and Maruthy (2018) studied speech perception in forty individuals with ANSD and reported no significant benefits of envelope enhancement in these individuals, irrespective of whether they had poor or good speech identification scores. Although both the studies (Balan & Maruthy, 2018; Narne & Vanaja, 2009a, 2012) have utilised exactly same procedures for envelope enhancement, the results are contradictory. A crucial aspect that can account for a part of this variance may be the use of different stimuli across the studies. Narne and Vanaja (2009a, 2012) used words to assess speech perception, which involve higher redundancy. On the other hand, Balan and Maruthy (2018) utilised monosyllables, which are known to be linguistically least redundant in nature. Also, they used stop consonants for testing which are most challenging to perceive by individuals with ANSD (Kumar & Jayaram, 2011). This may have hindered the improvement in speech perception with envelope enhancement in their study. Thus, one can speculate that the benefit derived from acoustic enhancement is at least partially affected by the type of stimuli being used to assess speech perception.

It can be hypothesised that if linguistically rich stimuli such as words or sentences are used to assess speech perception in individuals with ANSD, greater benefits of envelope enhancements will be derived. Since sentences involve greater linguistic and contextual cues than words, one can speculate a greater improvement in speech perception using sentences. In light of this, the present study used different test stimuli to assess the effect of envelope enhancement strategy on speech perception of individuals with ANSD.

1.2 Aim and Objectives of the Study

The aim was to investigate the effect of different type of stimuli on the perceptual benefit derived from envelope enhancement of speech in individuals with ANSD. The specific objectives of the study were,

1) to compare normal individuals and persons with ANSD for their speech identification scores of original and envelope enhanced monosyllables, words and sentences in different SNRs.
2) to compare the speech identification scores across monosyllables, words and sentences in individuals with ANSD.

1.3 Null hypotheses of the Study

The present study tested the following null hypotheses

1) There is no significant difference between normal hearing individuals and persons with ANSD in their speech identification scores of original and envelope enhanced monosyllables, words and sentences, in different SNRs.
2) There is no significant difference between the speech identification scores obtained across monosyllables, words and sentences in individuals with ANSD.

Chapter 2

REVIEW OF LITERATURE

This chapter is directed to provide an extensive review of the various acoustic enhancement strategies used to improve speech perception in individuals with auditory neuropathy spectrum disorder (ANSD). Furthermore, the review sheds light upon the effect of stimulus on speech perception. The review is presented under the following major sections:

1) Speech perception in ANSD
2) Acoustic enhancement strategies to improve speech perception in ANSD
3) Effect of stimulus redundancy on speech perception

2.1 Speech Perception in ANSD

2.1.1 Speech perception in quiet

Poor speech recognition is a hallmark of individuals with ANSD (Zeng, Kong, Michalewski, & Starr, 2005). This can be attributed to the impaired temporal processing abilities in these individuals, not commensurate to their hearing thresholds (Kumar & Jayaram, 2011; Narne & Vanaja, 2009b; Zeng et al., 2005). Previous investigations report that these individuals are unable to make use of available envelope and spectral cues for speech perception, which is directly associated with the disrupted neural synchrony of the eighth nerve seen in them (Rance, 2005; Zeng et al., 1999).

Typically in ANSD, speech perception is poorer than that seen in an equivalent degree of cochlear hearing loss (Starr, Picton, Sininger, Hood, & Berlin, 1996). However, not all individuals show peculiarly poor speech identification scores in quiet. This may be observed in patients with a less severe disease process (Rance, 2005). Some of the impaired psychoacoustic abilities such as reduced gap detection, reduced ability to follow fast and slow temporal modulation as evidenced by TMTF, and impaired frequency discrimination at low frequency are known to contribute to poor speech perception in these individuals (Rance, McKay, & Grayden, 2004; Starr et al., 1996).

Narne and Vanaja (2008) reported that individuals with ANSD are poorer in perceiving cues of voicing than those of manner or place of articulation. On the contrary, Gnanatheja and Barman (2011) found poor perception of all three types of cues by individuals with ANSD, with perception of manner cues being better compared to the other two cues. Rance and Barker (2008) compared perception of diphthongs, semivowels, and vowels, between ANSD and cochlear hearing loss groups. In the results, vowels were found to be similarly perceived in both the groups, while diphthong and semivowel perception were perceived poorly by those with ANSD.

Hassan (2011) reported relatively preserved perception of fricatives as opposed to other consonant groups, and attributed it to preserved high-frequency discrimination in these individuals. Narne and Vanaja (2008) reported impaired perception of nasals, and attributed this to the importance of low-frequency spectral cues in nasal perception. The authors also stated that persons with ANSD have trouble in the perception of stops, particularly in terms of place of articulation. They speculated that this could be due to impairment in utilizing the burst amplitude and formant transition. The difficulties in the perception of stop consonants is attributed to their impaired temporal processing (Kumar & Jayaram; 2011, 2013) and difficulty in perceiving fast modulations of speech (Zeng et al., 1999).

Prabhu, Avilala, and Barman (2011) studied perception of unfiltered speech and low-pass filtered speech with a cutoff frequency of 1700Hz in individuals with ANSD. They found no significant difference in perception, which they suggested may be possibly caused by the poor phase locking of low frequency information by Type I fibres. Based on their results, the authors speculated that individuals with ANSD may preferentially make use of high-frequency information to understand speech.

From the above studies, it can be inferred that while individuals with ANSD have intact perception of less dynamic cues for speech such as continuants (fricatives), they have trouble perceiving fast-changing cues as in stop consonants.

2.1.2 Speech perception in noise

Difficulty in perceiving speech in the presence of background noise is not unique to individuals with ANSD but is also seen in the individuals with cochlear hearing loss (Moore, 2003). However, the effect of noise is greater in individuals with ANSD than in those with cochlear hearing loss. Rance et al. (2007) obtained open-set word recognition scores for consonant-nucleus-consonant words in twelve children with ANSD, twenty children with cochlear hearing loss and twenty-five with normal hearing. The scores were obtained at three different SNRs (0dB, 5dB, & 10dB) and in quiet. It was shown that about 70% of performance could be sustained until 5dB SNR in children with normal hearing and those with cochlear hearing loss. However, in children with ANSD, the performance descended to 30% at 5dB SNR. Further, children with ANSD who had scores more than 60% in quiet condition maintained about 40% performance at 0dB SNR, whereas children with lesser than 60% scores in quiet dropped down to 20%.

Zeng and Liu (2006) reported that a person with ANSD had 90% score in the Bamford-Kowal-Bench Sentence test when presented in quiet: But the performance degraded to 40% and 5% at 10dB SNR and 0dB SNR respectively. Kraus et al. (2000) reported a single case study of a 24-year-old individual with ANSD in which the person showed 100% score in quiet but 10% score at +3dB SNR. Shallop (2002) found that individuals with ANSD having mild-to-moderate hearing loss had 100% score in quiet, which steeply dropped to 25% score at +15dB SNR and 0% score at +12dB SNR, when tested with the Hearing In Noise test. In simultaneous masking conditions, individuals with ANSD are found to display 10-20dB greater masking effect than the normal individuals (Kraus et al., 2000; Zeng et al., 2005). Houtgasten and Steeneken (1985) attributed poor speech-in-noise perception in these individuals to their poorer ability to process the signal envelope.

2.2 Acoustic Enhancement Strategies to Improve Speech Perception in ANSD

Many researchers have postulated different acoustic enhancement strategies for improving speech perception in individuals with ANSD (Hassan, 2011; Kumar & Jayaram, 2011; Mathai & Yathiraj, 2013; Narne & Vanaja, 2008; Zeng & Liu, 2006). The details of the strategies and their utility are described in the subsequent sections.

2.2.1 Clear speech

One means of improving speech intelligibility is to use clear speech. Clear speech involves three main acoustic characteristics; one, the presence of increased spectral energy at the mid-to-high frequencies; two, increased modulation which provides enhanced envelope cues; and three, the higher consonant-to-vowel ratio. Zeng and Liu (2006) compared the performance of 13 adults with ANSD in clear and conversational speech styles using speech sentences. Sentences in clear speech were, on average, twice as long as the equivalent sentences spoken in conversational speech. Significant improvement in speech perception was observed for clear speech in both quiet and noisy situations. An improvement in speech reception threshold by about 1.3dB was reported when silent gaps were introduced in conversational speech thereby, decreasing the rate of speech.

2.2.2 Spectral modification

Individuals with ANSD have been shown to perform poorly in frequency discrimination tasks than individuals with normal auditory abilities (Barman, 2008; Starr et al., 1991), specifically at lower frequencies (Barman, 2008; Zeng et al., 2001). In view of this, attempts have been made to enhance the spectral cues of speech in order to facilitate speech perception of individuals with ANSD.

Narne (2008) studied the effect of upward spectral shift on speech perception in individuals with ANSD. Lower frequency information (below 500Hz) was shifted linearly to the high frequency region (above 500Hz). The results showed degraded perception in individuals with ANSD following the spectral shift. It hypothesised that this may be due to the change in frequency coding of the auditory system.

Prabhu, Avilala, and Barman (2011) reported the effects of spectral modification on speech perception in 12 individuals with ANSD. Using Adobe Audition software, the words were filtered with a low pass cut-off of 1700Hz and a high pass cut-off of

1700Hz with an attenuation rate of 115dB/octave. In comparison to the unfiltered speech, the perception of low pass filtered speech was found to be poorer in individuals with ANSD. Whereas, the perception of high pass and unfiltered speech were comparable. The degraded perception of low pass filtered speech was attributed to the difficulty in phase locking in individuals with ANSD. Moreover, it was postulated that spectral modification which transforms lower frequency energy to higher frequency energy may help in improving speech perception in these individuals.

Narne, Barman, Deepthi, and Shachi (2014) studied the effect of combined spectral and temporal enhancement in 10 individuals with ANSD. Twenty vowel-consonant-vowel syllables were used in the study. The authors utilized a 'Companding' algorithm given by Bhattacharya and Zeng (2007). The acoustic analysis of the companded stimuli showed preservation of spectral peaks at -5dB SNR and a higher envelope, than the original stimuli. The results of syllable identification showed improvement in quiet and at 15dB SNR.

On the contrary, Balan and Maruthy (2018) utilised stop consonants in the context of /a/ to study the effect of companding on speech perception in forty individuals with ANSD. The procedure described by Turicchia and Sarpeshkar (2005) was used to generate the companded stimuli. The authors reported no significant benefit of companding in these individuals, in quiet as well as at 0dB SNR.

2.2.3 Temporal modification

Time- scale modification of speech: Psychoacoustic studies using gap detection and temporal masking (Kraus et al., 2000) have shown that individuals with ANSD find difficulty in perceiving short duration acoustic stimuli (Zeng et al., 1999, 2005). This indicates that short acoustic events such as bursts, transitions and voice onset time which are vital for speech perception are of particular difficulty for individuals with ANSD. Numerous efforts have been made to modify the stimuli, such that, these short duration stimuli are perceived better (Kumar & Jayaram, 2011, 2013; Hassan, 2011; Mathai & Yathiraj, 2013).

Kumar and Jayaram (2011) assessed for syllable identification in 30 individuals with ANSD in comparison to their age-matched normal hearing individuals. Eight consonant-vowel pairs consisting both voiced and unvoiced consonants were taken. The syllables were modified by lengthening the transition duration. The lengthening was done based on the just-noticeable differences (JND) for transition duration. The JNDs were obtained by calculating the difference between unmodified and modified stimuli such that a 69% score is achieved. The transition duration was lengthened in multiples of JNDs. The authors reported JNDs to be four times larger for the ANSD group than that of the normal hearing group. Also, in the ANSD group, the speech identification scores obtained for unmodified stimuli ranged from about 0-87% while for the modified stimuli the scores ranged from 0-100%. Based on their findings, the authors recommended lengthening the transition duration, and attributed the improvement in perception to the reduction in modulation frequency, rather than change in modulation depth. Furthermore, Kumar and Jayaram (2013) studied the combined effect of lengthening the burst duration, voice onset time and transition duration on syllable identification. The results showed that the speech identification scores obtained by lengthening the burst and voice onset time along with the transition duration was not significantly better than the scores obtained by just manipulating the transition duration.

Hassan (2011) reported the effect of lengthening formant transitions on syllable identification in fourteen adults with ANSD having bilateral moderate hearing loss. Four Arabic CV pairs were taken in which two classes of speech sounds, namely, stops and fricatives were chosen. The inter-stimulus interval between the CV pairs was reduced from 1000ms to 300ms in steps of 100ms in the natural stimuli. For the processed stimuli, inter-stimulus interval as well as formant transitions were expanded. Later, the minimum inter-stimulus interval required to discriminate the CV pairs was determined. The results showed that lower inter-stimulus intervals were required to discriminate between the CV pairs when the processed stimuli were used. This indicated that expanding the formant transition was much more important than expanding the inter-stimulus interval. Also, the stop consonants /k/ and /g/ in particular, required larger inter-stimulus interval for perception, highlighting the fact that ANSD individuals have difficulty in the perception of stop consonants than fricatives. Fricatives are perceived better due to greater ability of these individuals to discriminate higher frequencies.

Mathai and Yathiraj (2013) reported the effect of time-scale modification, as well as, the effect of vowel context on the perception of vowel-consonant-vowel (VCV) pairs. Eight stops and two liquids were chosen in the context of vowels /a/, /i/ and /u/. The stimuli were modified by three time-scale factors i.e. 25%, 35% and 50% using 'pitch synchronous and overlap and add' algorithm. The results indicated that the 25% stretch condition led to a significant improvement in inter-vocalic consonant perception across the three vowel context. This improvement was attributed to the lengthening of the consonantal portion of the stimuli. The 35% stretching led to a significant improvement only in the context of /a/ while 50% stretching lead to further decline in perception across all vowel-contexts. The authors attributed it to the excessive backward masking caused by the following vowel in VCV syllables. The authors recommended stretching of the complete signal rather than stretching specific acoustic landmarks such as burst or transition for better perception in individuals with ANSD. The findings indicated that speech perception in individuals with ANSD is highly dependent on the context.

Envelope enhancement: Several psychophysical studies (Kumar & Jayaram, 2005; Rance, McKay, & Grayden, 2004; Zeng, Oba, Garde, Sininger, & Starr, 1999) suggested that limited speech perception in individuals with ANSD is related to their inability to follow amplitude variations in speech, hinting at envelope enhancement to help speech perception in these individuals. Narne and Vanaja (2009b) tried to simulate the perceptual deficits of individuals with ANSD in normal hearing individuals. The perception of temporally distorted speech was studied in normal hearing individuals. It was noted that the perception of temporally distorted speech in normal hearing individuals was similar to the perception in individuals with ANSD. Further, it was shown that the envelope enhancement of speech improved perception in simulated conditions of mild and moderate degree of impairment. This indicated that temporal enhancement of envelope can compensate for the perceptual difficulties in individuals with ANSD.

Narne and Vanaja (2008) investigated the perception of envelope enhanced CV pairs in eight individuals with ANSD. The envelope of each pair was increased by 15dB for four different bandwidths. ‘overlap and add’ algorithm in PRAAT software was used for this purpose. The results showed greater improvement for broader envelope bandwidth (3-30Hz) than narrower bandwidths (3-10Hz, 3-20Hz). Also, an improvement in perception using envelope enhancement was seen only in six individuals, while the two individuals with poorer speech identification scores showed no improvement. The sequential information transfer showed that place and manner of articulation information were transmitted better in the envelope enhanced condition. Significant improvement in the perception of place of articulation of stop consonants was noted in the enhanced condition reflecting that envelope enhancement of speech can compensate for the deficits in following faster amplitude variations seen in individuals with ANSD.

Using the envelope enhancement scheme given by Apoux, Tribut, Debruille, and Lorenzi (2004), Narne and Vanaja (2009a) studied the effect of envelope enhancement on the speech perception of 15 individuals with ANSD. The scheme increased the envelope for consonant portion while compressing the vowel portion, thus enhancing the consonant-to-vowel ratio. The perception was assessed in quiet and with-noise conditions (0, 5 & 10dB SNR). The results showed benefits for individuals having speech identification scores greater than 50% in all the three SNRs whereas, in those with speech identification score lesser than 50%, the benefit was seen only in quiet and 10dB SNR.

Narne and Vanaja (2012) studied the effect of envelope enhancement and high-pass filtering (500Hz) separately, on speech perception of 12 individuals with ANSD. A mean improvement of 18.3% in the word identification scores was observed using envelope enhancement. However, high-pass filtering did not improve speech perception. The authors suggested that elimination of low frequencies is not a reasonable solution to compensate for the temporal deficits seen in these individuals.

On the contrary, Balan and Maruthy (2018) studied the effect of envelope enhancement on speech perception in forty individuals with ANSD. Similar to Narne and Vanaja (2009a) study utilised the envelope enhancement scheme given by Apoux et al. (2004). Stop consonants in the context of /a/ were used to assess speech perception. The identification was assessed in a closed-set task in quiet as well as 0dB SNR. The authors reported no significant benefit of envelope enhancement in these individuals, irrespective of whether they had poor or good speech identification scores.

2.3 Effect of Stimulus Redundancy on Speech Perception

The primary purpose of assessing speech perception is to estimate how well a listener understands speech in a controlled environment which in turn reflects how they may perform in everyday listening situations (Giolas & Epstein, 1963). For individuals with hearing impairment, it gives additional insights to the degree of communication handicap caused due to hearing loss. Thus, it provides an estimate of the difficulty in understanding speech (Davis & Silverman, 1970; Epstein, 1978; Silverman & Hirsh, 1995).

Various stimuli such as nonsense syllables, words, and sentences have been used to test speech perception. Each stimulus differs in terms of redundancy, scoring pattern, and its relation to everyday speech which leads to differential effects on speech perception.

The use of nonsense syllables to assess speech perception has several advantages over other test stimuli. They are non-redundant in nature (Carhart, 1965) and independent of linguistic cues that could contaminate the estimate (Berger, 1969). They are easier to construct than other test stimuli (Egan, 1948) and are not influenced by the listener's vocabulary. However, these are often confusing to the listener (Carhart, 1965). Monosyllabic words are considered to be less precise than nonsense syllables, while bisyllabic words are less analytical than monosyllabic words as they provide additional cues for speech intelligibility (Hirsch, 1952). Sentences, on the other hand, are rich in contextual cues and are considered to reflect realistic situations much more effectively than other stimuli. It not only assesses how an individual processes acoustic cues but also provides additional insights into the subject's ability to use linguistic and contextual cues to perceive speech. Nevertheless, it is usually difficult to determine whether a listener perceived the entire stimuli or used contextual cues to fill-in the missing information (Silverman & Hirsh, 1995).

Nittrouer and Boothroyd (1990) reported the effects of sentence context on speech perception in normal hearing adults and children. Three types of sentences were constructed, namely, high predictability, low predictability, and zero predictability sentences. The high predictability sentences were semantically and syntactically intact, the low predictability sentences were semantically anomalous while syntactically intact, and the zero predictability sentences were both semantically and syntactically incorrect. It was shown that, with the addition of semantic context, the scores for both the groups increased. In another study by Miller, Heise, and Lichten (1951) speech perception of words was assessed in isolation and in the context of sentence. It was reported that in a noisy environment, words were more intelligible in the context of a sentence than in isolation. Zust and Tschopp (1995) also studied the effect of context on speech recognition using Basel Sentence Understanding test. The test consisted of two types of sentences: high predictability final word and low predictability final word. The speech recognition thresholds obtained for high predictability sentences were much lower than low predictability ones suggesting the significant effect of context on speech recognition. Giolas and Duffy (1970) studied the intelligibility of words in a sentence when words had varying predictability. It was shown that the predictability of a word has an influence on its intelligibility.

In individuals with ANSD, the differential effects of acoustically enhanced stimuli on speech perception can be observed in the existing literature. Mathai and Yathiraj (2013) reported consonant perception to vary depending on the vowel-context. Significantly better consonant perception was reported in the context of /a/ and /u/ opposed to that of /i/. Stop consonants have been found to be most challenging for individuals with ANSD (Hassan, 2011; Kumar & Jayaram, 2011). Hassan (2011) witnessed variation in performance depending on the CV pair used to assess speech perception. The author used various classes of consonants in the context of /a/ and found stop consonants to be most difficult and fricatives to be least difficult compared to other consonants.

Thus, it is clear from the literature that speech perception varies depending on the stimuli used. A shred of introductory evidence to this is also shown with use of various acoustic enhancement strategies. Therefore, it can be hypothesised that the benefit derived from envelope enhancement strategy is also influenced by the stimuli. This warrants the need to systematically investigate the differential effects of envelope enhanced stimuli on speech perception. This might further help in deriving clinical benefit of envelope enhancement strategy by making the previous investigations comparable.

Chapter 3

METHODS

The present study incorporated a quasi-experimental mixed group design to study the overall null hypothesis that there is no significant effect of envelope enhancement on the speech identification of individuals with auditory neuropathy spectrum disorder (ANSD). The following method was adopted in the study.

3.1 Participants

There were two groups of participants in the study: ANSD group and the Control group. The ANSD group had 10 participants (2 males & 8 females) diagnosed with ANSD, while the control group included 15 age-matched individuals with normal auditory abilities.

ANSD was diagnosed by a qualified audiologist based on the criteria recommended by Starr, Sininger, and Praat (2000). The participants were in the age range of 14 to 36 years (Mean = 22.8 years, SD = 7.11). Seven of the participants had sensorineural hearing loss and the severity of the hearing loss ranged up to moderate degree. The remaining three had normal hearing sensitivity. Of the seven participants who had sensorineural hearing loss, three had minimal hearing loss, two had mild hearing loss and another two had moderate degree of hearing loss. Figure 3.1 represents the mean air-conduction thresholds of the participants in this group. The duration of hearing loss ranged from a minimum of 3 months to a maximum of seven years. All the participants of this group had acquired ANSD postlingually. The individual demographic details and audiological profile of participants in the ANSD group are provided in Appendix 1.

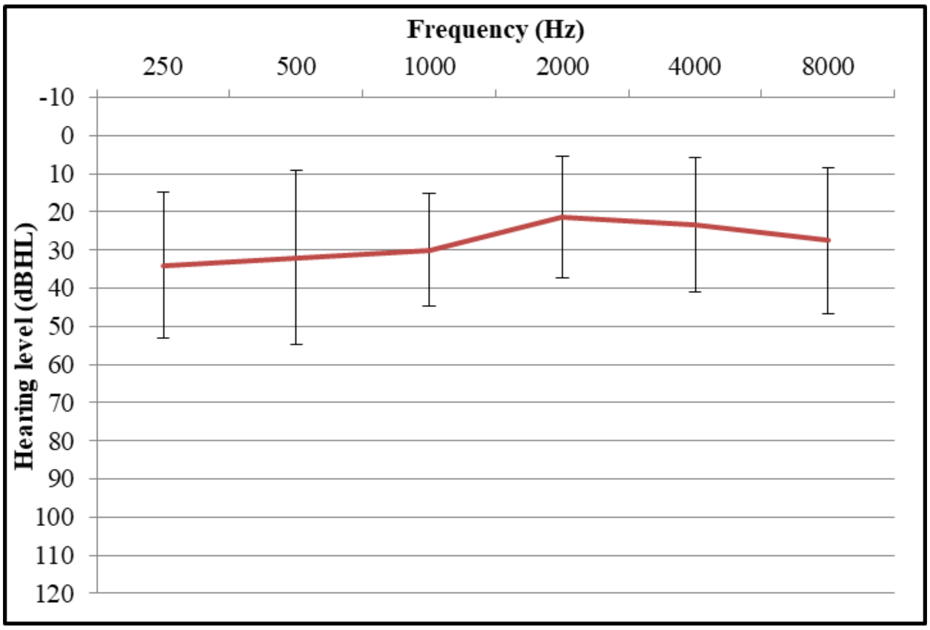

Figure 3.1: Mean and standard deviation (1S.D.) of the air-conduction thresholds at the audiometric frequencies of the better ear in participants with ANSD.

The participants of the control group had normal auditory abilities. They were age-matched to the participants in the ANSD group (Mean = 22.06 years, SD = 5.65). Through a structured interview, it was confirmed that none of them had any history of speech, hearing and neurological disorders or deficits. None had difficulty in understanding speech in daily listening conditions. Their speech identification scores in quiet ranged from 90% to 100%. They had type 'A' tympanogram with the presence of both ipsilateral and contralateral reflexes indicating normal middle ear function in both the ears. Participants in this group had hearing thresholds within 15dB HL at octave frequencies between 250Hz and 8kHz (ANSI, 1996). Auditory brainstem responses and transient evoked otoacoustic emissions revealed normal findings for all the participants of this group.

The participants of both the groups were native speakers of Kannada. The testing procedure was explained to the participants prior to their inclusion, and an informed consent was obtained from all the participants. The test procedures used adhered to the AIISH Ethical guidelines for bio-behavioral research (Venkatesan, 2009).

3.2 Instrumentation and Softwares

Several technical equipments and softwares were utilized for stimulus generation, candidacy assessment, and the test administration. The specific equipments and softwares and their purpose in the study are detailed below.

a) MATLAB-7 (The Math Works, Natick, USA) was used for the generation of acoustically enhanced monosyllables, words and sentences.
b) Resampling, editing, and loudness normalisation of the audio stimuli were done using Adobe Audition software version 3 (Adobe Systems Incorporated, San Jose, CA, USA).
c) A calibrated 2-channel GSI Audiostar pro diagnostic audiometer with TDH-50 headphone was used to obtain the air-conduction thresholds and also for speech audiometry. Bone conduction thresholds were evaluated using Radio ear B-71 bone vibrator attached to the same Audiometer.
d) Calibrated GSI Tympstar (version 2) was used to carry out tympanometry and acoustic reflex evaluation.
e) Biologic auditory evoked potential system (version 7.2.1) was used to record and analyze auditory brainstem response.

f) ILO V6 Echoport (version 6.40.0.0) was used to record transient evoked otoacoustic emissions.

g) A laptop with Intel(R) Core (TM) i36006U) processor was used to play the recorded stimuli.

h) Sennheiser headphone (HDA-300) was used to deliver the auditory stimuli.

i) Unidirectional microphone (AHUJA AUD-101 XLR) was used for audio recording of the responses.

3.3 Test Environment

All the testing were carried out in an acoustically shielded room where the noise levels were within the permissible limits (ANSI S3.1; 1991). The room used for recording auditory brainstem responses was also electrically shielded.

3.4 Test Stimuli

In the present study, both ANSD and control groups were tested for their speech identification in different listening conditions. The participants of the ANSD group were tested in two listening conditions, namely, in quiet and at 0dB SNR. Whereas, the participants of the control group were tested in three with-noise conditions i.e. in the presence of noise with SNR at 0dB, -5dB and -10dB. They were not tested in quiet condition as they were likely to obtain 100% identification scores resulting in ceiling effect. The speech identification scores were obtained for both original and envelope enhanced stimuli.

Three different speech stimuli were used in the present study; monosyllables, words, and sentences. All the speech stimuli were in Kannada language. The details of the stimuli used are as given below.

a) Monosyllables: A standardised set of twenty-one recorded consonant-vowel (CV) syllables with consonants / p, b, m, t̪, d̪, t, d, ɖ, s, ʃ, tʃ, dʒ, r, l, ɭ, n, ɳ, j, v, k, g / and vowel /a/ were used. Except /ba/, the monosyllables were non-meaningful in Kannada language.
b) Words: The recorded version of the phonemically balanced word identification test in Kannada, developed by Yathiraj and Vijaylakshmi (2006) was used. The test contains four standardised word lists, each with 25 phonemically balanced bisyllabic words of equal difficulty. In the present study, all four lists were used.
c) Sentences: The first four recorded sentence lists were taken from the standardised 'Sentence test in Kannada language for adults' (Geetha, Kumar, Manjula, & Pavan, 2011). Each list consisted of 10 sentences. The sentences included in the test are considered to be highly natural, low in predictability, and equivalent. The sentences in each list are phonemically balanced. The mean identification score at -5dB SNR for all the 25 lists included in the test is 54%.

The stimuli were further processed using the technique of envelope enhancement. The envelope enhanced stimuli were generated by adopting the procedure used by Apoux, Tribut, Debruille, and Lorenzi (2004). MATLAB-7 (The Math Works, Natick, USA) was used for this purpose. The stimuli were divided into four bands using band-pass filters (3rd order Butterworth) of 150-550, 550-1550, 1550-3550, and 3550-8000 Hz. The temporal envelope E (t) was extracted from each band by full-wave rectification and low-pass filtering (3rd order Butterworth) with a cut-off frequency of 32 Hz. This cut-off frequency was selected based on the findings of Narne and Vanaja (2008), wherein mean consonant identification score was reported to be best in this cut-off frequency. The extracted envelope was either left intact or raised to the power K, with a value of K ranging from 4 to 0.3 as a function of the instantaneous envelope amplitude value (Ei). The exponent K was selected such that maximum expansion (K max = 4) was applied to the lowest envelope amplitude value (E min), and the maximum compression (K min = 0.3) was applied to the highest envelope amplitude value. The expression for K is given in Equation 1.

$$Ki\ (b) = e\ \left(\frac{Ei - Emin}{T}\right)(Kmax - Kmin) + Kmin \quad \text{.......Eq. (1)}$$

Wherein, b represents a specific band, T is a constant (0.5 for each stimulus) within the band.

The minimum envelope amplitude value (E min) was computed over the whole signal duration within the band. A correction factor was then obtained by computing the ratio of the expanded and original envelopes for each sample. The obtained correction factor was then multiplied with the original band-pass signal at each corresponding point in time, and finally, the resulting bands were added to get the enhanced signal and were low-pass filtered (3rd order Butterworth filter) with a cut-off frequency of 8000 Hz. The RMS amplitude of the expanded signals was equated to that of original signals. Syllables, words, as well as sentences were processed using this scheme. Figure 3.2 shows the envelopes of the original and envelope enhanced sample stimuli, overlaid on each other.

In order to generate speech-shaped noise, the spectral components of the speech stimuli were derived using Fourier transform. The phases of these spectral components were then randomised and the resultant was converted back into time-domain using an Inverse Fourier transform. The above steps were carried out to generate the speech-spectrum-shaped noise. MATLAB-7 (The Math Works, Natick, USA) was used for this purpose.

Furthermore, the RMS level of the speech signal and the noise was normalised using Adobe Audition software version 3. Both the envelope enhanced and the original stimuli were mixed with their respective speech-spectrum-shaped noise using MATLAB-7. The speech signals and the noise were mixed at 0dB, -5dB, and -10dB SNRs. The stimulus conditions and the total number of stimuli presented in each condition, in each group is represented in Table 3.1.

3.5 Test Procedure

Two types of assessments were performed on every participant; (1) Candidacy assessment and (2) experimental test procedure.

3.5.1 Candidacy assessment

All the participants were subjected to candidacy assessment to ensure that they met all the inclusion criteria of the study. The procedure included case history/structured interview, pure-tone audiometry, speech audiometry, Immittance evaluation, Otoacoustic emissions (OAEs), Auditory Brainstem Responses (ABR), and neurological evaluation.

Pure-tone thresholds were estimated at octave frequencies between 250 Hz and 8000 Hz in air conduction, and between 250 Hz and 4000 Hz in bone conduction mode, using the modified Hughson and Westlake procedure (Carhart & Jerger, 1959). Speech recognition thresholds were obtained monaurally using pair-words in Kannada developed in the department of Audiology, AIISH, Mysuru. Speech identification score was obtained monaurally at 40dBSL (re: Speech Recognition Threshold) for phonemically balanced word test developed by Yathiraj and Vijayalakshmi (2005).

Tympanogram and acoustic reflex thresholds were measured using 226 Hz probe tone. Ear canal volume, static admittance and tympanometric peak pressure were noted from the tympanogram. Ipsilateral and contralateral acoustic reflex thresholds were measured at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz in both the ears.

Transient evoked otoacoustic emissions (TEOAEs) were measured for clicks presented at 80 dB +/-5 dB pe SPL using ILO V6 Echoport (version 6.40.0.0) equipment. TEOAEs were considered to be present if the waveform reproducibility was more than 75% and the overall amplitude was more than 6dB in at least 3 consecutive frequencies of measurement.

ABR was recorded using Biologic Navigator evoked potential system (version 7.2.1). The standard protocol recommended in Hall (2007) for click-evoked ABR was used. Each recording was repeated to ensure replication of the responses.

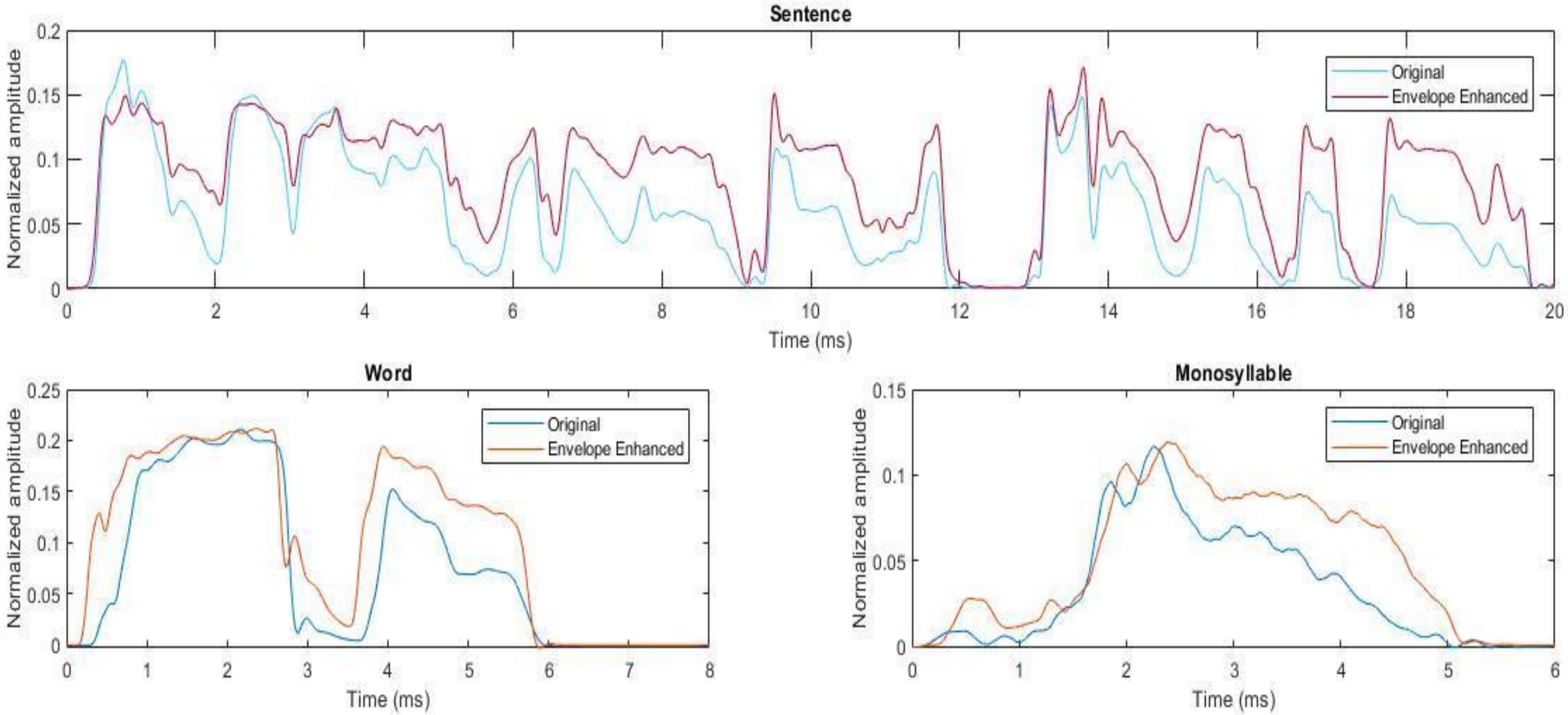

Figure 3.2: Envelopes of a sample sentence (/magu malagıruvaːga haṯ̪ṯ̪ıra hogabɛːɖa/), word (/oːd̪u/), and monosyllable (/dʒa/) in the original and envelope enhanced condition.

3.5.2 Experimental test procedure

All the participants who met the inclusion criteria were subjected to the experimental test procedure. In the experimental procedure, each participant was individually tested for their speech identification in different stimulus conditions. The participants were made to listen to speech tokens (envelope enhanced & original monosyllables, words & sentences). The ear which had better speech identification scores in the preliminary evaluation was selected for testing. This is in accordance with the fact that previous investigations have shown no improvement in perception using envelope enhanced stimuli in individuals with ANSD having lower speech identification scores (Narne & Vanaja, 2009a).

For the participants in the ANSD group, the speech identification scores for monosyllables, words, and sentences were obtained in two listening conditions, namely, in quiet and in 0dB SNR. The speech identification scores were obtained using both original and envelope enhanced stimuli. The control group was also subjected to speech identification testing for both envelope enhanced and original stimuli. Monosyllables, words, and sentences were presented in three with-noise conditions, at SNR of 0dB, -5dB, and -10dB.

Recorded speech stimuli were played from a calibrated laptop. Sennheiser headphone (HDA-300) was used to listen to the auditory stimuli. The stimuli were presented at the participant's most comfortable level (MCL). The MCL was estimated by presenting a sentence at each intensity level starting from 40dBHL to 80dBHL in 5dB steps. The words and sentences were presented only once while monosyllables were presented 5 times in a randomized order. The participants were given practice trials before beginning the actual testing to ensure complete understanding of the task. They were instructed to repeat the speech tokens heard by them. A two-minute break was given after every two conditions. However, the testing was completed in a single day. Also, it was ensured that different word and sentence lists were used for different listening conditions to avoid familiarisation to the stimuli.

Table 3.1: Total number of stimuli presented in different listening conditions in the two groups of participants

Group	Stimulus Condition	Stimulus Type	Listening condition	Stimulus Number	Repetition	Subtotal	Total
ANSD	Original	Monosyllables	2	21	5	210	560
		Words	2	25	0	50	
		Sentences	2	10	0	20	
	Envelope enhanced	Monosyllables	2	21	5	210	
		Words	2	25	0	50	
		Sentences	2	10	0	20	
Control	Original	Monosyllables	3	21	5	315	840
		Words	3	25	0	75	
		Sentences	3	10	0	30	
	Envelope enhanced	Monosyllables	3	21	5	315	
		Words	3	25	0	75	
		Sentences	3	10	0	30	

3.6 Scoring of the Responses

The speech identification scores were calculated by counting the number of correct responses while using monosyllables and words. The speech identification score for sentences was determined by counting the number of keywords spoken correctly. Each sentence consisted of four keywords. A score of 'one' was given for a correct response while a score of ‘zero’ was given for an incorrect response. Raw score was calculated for each participant based on the correct responses obtained. Accordingly, the maximum possible score was twenty-one for monosyllables, twenty-five for words and forty for sentences. Subsequently, the raw scores were converted into percentage, which in turn was subjected to further statistical analysis.

Chapter 4

RESULTS

The present study aimed to investigate the effect of different types of stimuli on the perceptual benefit derived from envelope enhancement of speech in individuals with ANSD. Percentage of speech identification was the dependent variable, whereas group (ANSD versus control), stimulus condition (original & envelope enhanced), and stimulus type (monosyllables, words & sentences) were the independent variables in the study.

The group data was statistically analysed using Statistical Package for Social Sciences (SPSS, Version 20). Initially, the data of both the groups were tested for its distribution using Shapiro-wilk test of normality. There were 12 variables in the ANSD group and 18 variables in control group. The results of the test (Appendix 2) showed that the data were not normally distributed in most of the variables, in both the groups. Hence, non-parametric tests such as Mann-Whitney U test, Friedman test and Wilcoxon signed rank test were used for further statistical analysis. The results obtained in the present study are reported under following major headings;

1) Effect of stimulus on speech identification of individuals with ANSD
2) Effect of stimulus on speech identification of individuals of control group
3) Effect of group on speech identification

4.1 Effect of Stimulus on Speech Identification of Individuals with ANSD

The analysis in this section was meant to tap the effect of envelope enhancement (operationally defined as stimulus condition) and different stimulus type (monosyllables, words & sentences) on the percentage of speech identification. The results obtained are reported separately for the two variables.

4.1.1 Effect of stimulus condition

The effect of stimulus condition was assessed by comparing the percentage of speech identification obtained for the original and envelope enhanced stimuli. Figure 4.1.A and 4.1.B show the median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained in individuals with ANSD, for original and envelope enhanced stimuli, in quiet and 0dB SNR respectively. The figures show the comparison in the three stimulus types.

From Figure 4.1, it can be observed that the median speech identification obtained for original stimuli was higher than that of envelope enhanced stimuli. This is true for all the three stimulus types in both quiet and 0dB SNR. The comparison of the two stimulus conditions using Wilcoxon sign rank test showed that, in quiet, there was a significant difference between the original and envelope enhanced stimuli in words ($Z = -1.96$, $p = 0.05$) and sentences ($Z = -2.38$, $p = 0.01$). But, there was no significant difference in monosyllables ($Z = -1.36$, $p = 0.17$).

On the contrary, at 0dB SNR, there was a significant difference between the two stimulus conditions only in words ($Z = -2.38$, $p = 0.01$), while there was no significant difference in monosyllables ($Z = -1.73$, $p = 0.08$) and sentences ($Z = 0.00$, $p = 1.00$).

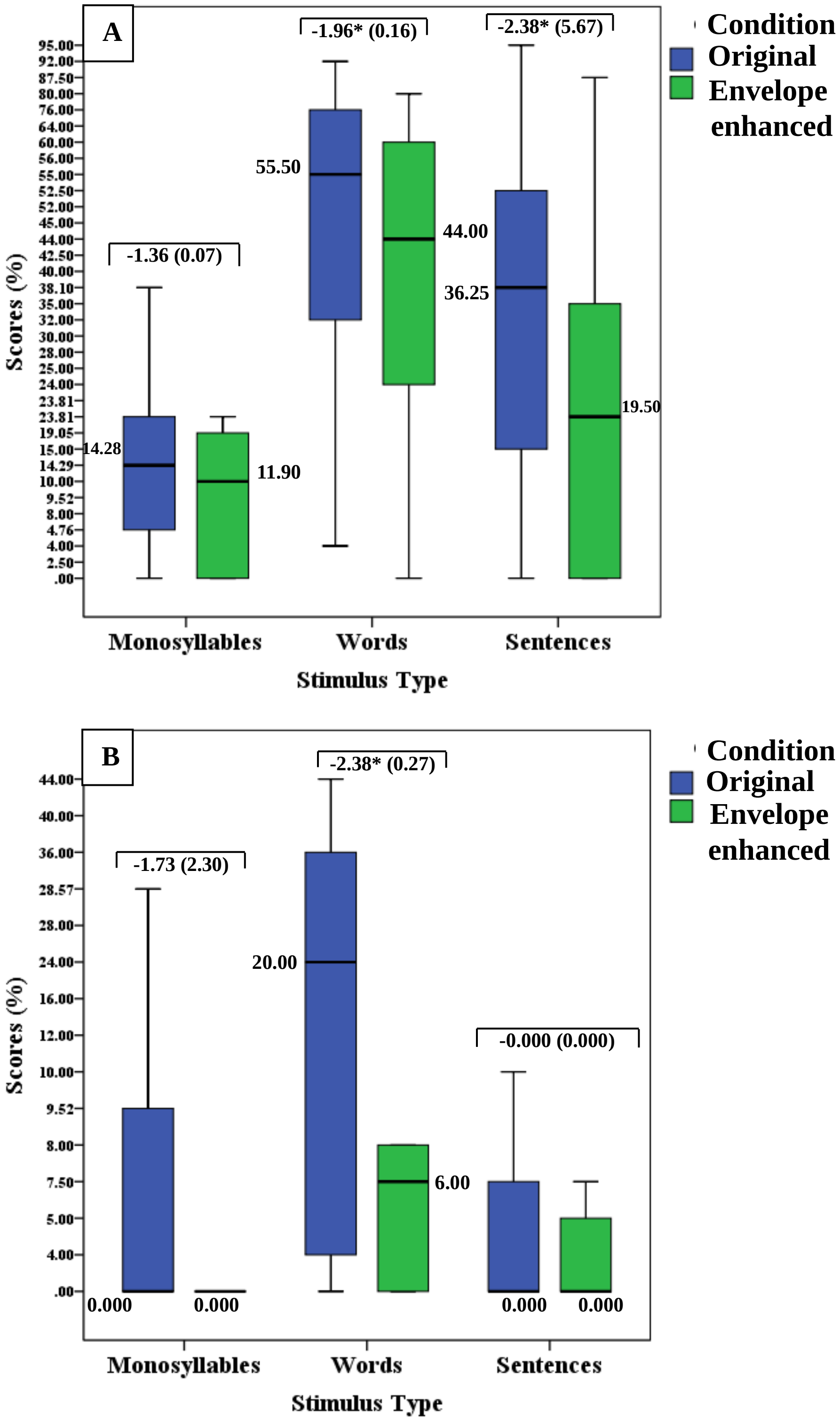

Figure 4.1: Median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained in individuals with ANSD for original and envelope enhanced stimuli, for the three stimulus types, in quiet (4.1.A) and 0dB SNR (4.1.B). The error bars depict minimum and maximum scores. Wilcoxon Z and the effect size (in parentheses) are provided.

Note: * indicates significant difference ($p < 0.05$).

4.1.2 Effect of stimulus type

To derive the effect of stimulus type, percentage of speech identification across the three stimulus types (monosyllables, words & sentences) was compared separately in quiet and 0dB SNR. The results obtained for the original and envelope enhanced stimuli are reported separately.

Results of original stimuli: Figure 4.2 shows the median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained across the three stimuli types, in quiet and 0dB SNR, in individuals with ANSD, for the original stimuli.

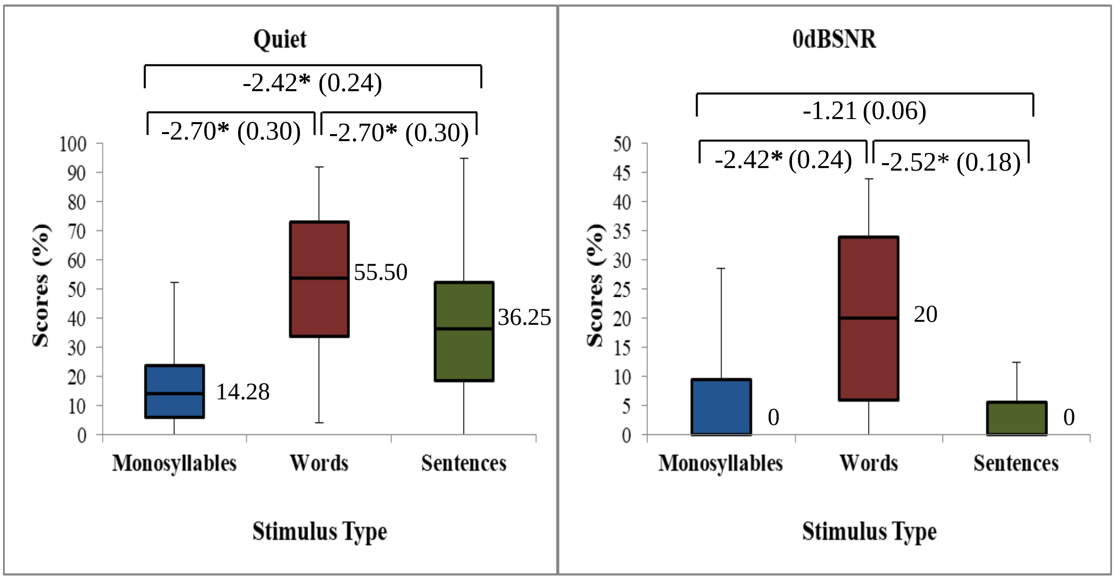

Figure 4.2: Median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained across the three stimulus types, in quiet and 0dB SNR, in ANSD group, for the original stimuli. The error bars depict minimum and maximum scores. Wilcoxon Z and the effect size (in parentheses) are provided. Note: * indicates significant difference ($p < 0.05$).

In both quiet and 0dB SNR, the median percentage of speech identification was maximum for words. While in quiet, the median identification was higher in sentences compared to monosyllables, the median was same between the two at 0dB SNR. The results of Friedman test showed a significant main effect of stimulus type in quiet [□^{2} (2) = 12.35, $p < 0.01$] as well as in 0dB SNR [□^{2} (2) = 8.58, $p = 0.01$] for the original stimuli. The pair-wise comparison using the Wilcoxon signed rank test showed that there was a significant difference across all the three stimulus types in quiet (Results shown in Figure 4.2). Whereas at 0dB SNR, significant difference was seen between words and monosyllables, and, words and sentences. There was no significant difference between sentences and monosyllables at 0dB SNR.

Results of envelope enhanced stimuli: Figure 4.3 shows the median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained across the three stimuli types, in quiet and 0dB SNR, in individuals with ANSD, for the envelope enhanced stimuli.

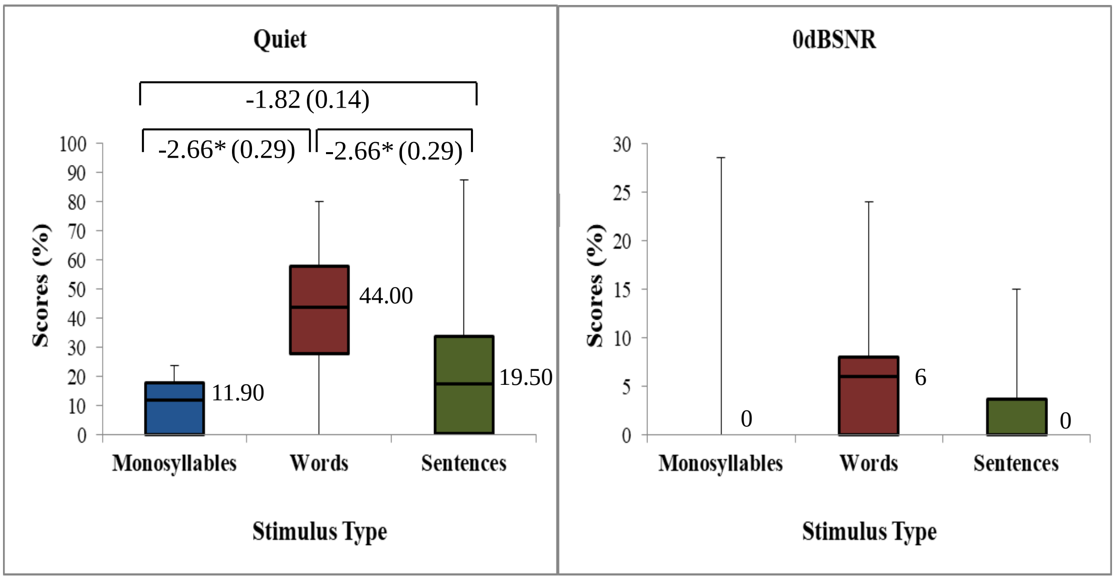

Figure 4.3: Median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained across the three stimulus types, in quiet and 0dB SNR, in ANSD group, for the envelope enhanced stimuli. The error bars depict minimum and maximum scores. Wilcoxon Z and the effect size (in parentheses) are provided.

Note: * indicates significant difference ($p < 0.05$).

Similar to the results of original stimuli, the median percentage of speech identification in envelope enhanced stimuli was maximum for words in quiet as well as 0dB SNR. While the median identification of sentences was higher than monosyllables in quiet, the two were same at 0dB SNR. The results of Friedman test showed a significant main effect of stimulus type in quiet [χ^2 (2) = 13.77, $p < 0.01$], but not in 0dB SNR [χ^2 (2) = 4.66, $p = 0.09$]. The subsequent pair-wise comparison (for the data of quiet) using the Wilcoxon signed rank test showed (Figure 4.3) that there was a significant difference between words and monosyllables, and words and sentences. There was no significant difference between monosyllables and sentences in quiet.

4.2 Effect of Stimulus on Speech Identification of Individuals of Control Group

The analysis in this section was meant to tap the effect of envelope enhancement and different stimulus types on the percentage of speech identification in individuals of control group. The results obtained are reported separately for the two variables.

4.2.1 Effect of stimulus condition

In the control group, unlike in ANSD group, speech identification was assessed only in with-noise condition at three SNRs (0dB SNR, -5dB SNR & -10dB SNR). Figure 4.4.A, 4.4.B and 4.4.C show the median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained in individuals of control group, for original and envelope enhanced stimuli, in 0dB, -5dB and -10dB SNR respectively. The figures show the comparison in the three stimulus types.

From Figure 4.4, it can be observed that the median speech identification differed between original and envelope enhanced stimuli. The comparison of the two stimulus conditions using Wilcoxon sign rank test showed that, at 0dB SNR, there was no significant difference between the original and envelope enhanced stimuli in monosyllables ($Z = -1.81$, $p = 0.07$), words ($Z = -2.23$, $p = 0.06$) and sentences ($Z = 0.08$, $p = 0.41$). A similar trend was observed at -5dB SNR, wherein there was no significant difference between the two stimulus conditions in monosyllables ($Z = -0.24$, $p = 0.80$), words ($Z = -1.73$, $p = 0.08$) and sentences ($Z = 0.36$, $p = 0.71$). On the contrary, at -10dB SNR, percentage of speech identification of envelope enhanced stimuli was significantly lower than the original stimuli in all the three stimulus types: monosyllables ($Z = -2.39$, $p = 0.01$), words ($Z = -3.41$, $p < 0.01$), and sentences ($Z = -2.06$, $p = 0.03$).

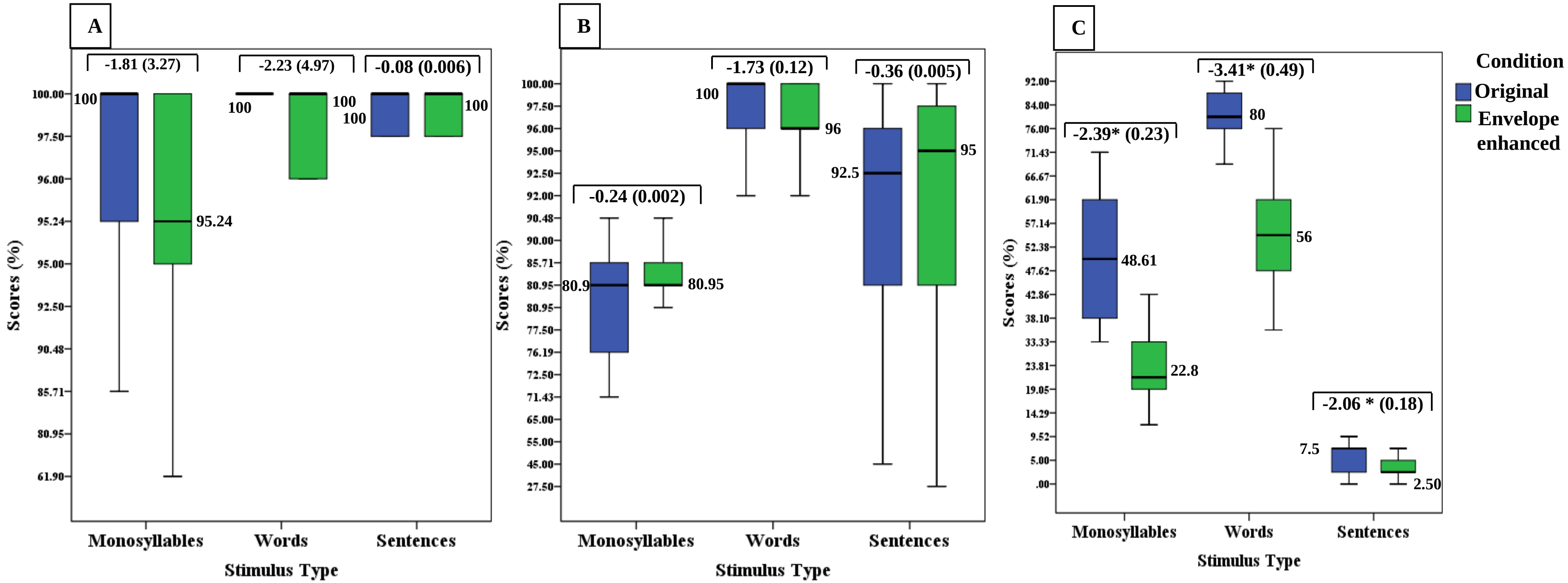

Figure 4.4: Median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained in individuals of control group for original and envelope enhanced stimuli, for the three stimulus types, at 0dB SNR (4.4.A), -5dB SNR (4.4.B) and -10dB SNR (4.4.C). The error bars depict minimum and maximum scores. Wilcoxon Z and the effect size (in parentheses) are provided.

Note: * indicates significant difference ($p < 0.05$).

4.2.2 Effect of stimulus type

To derive the effect of stimulus type in the control group, percentage of speech identification across the three stimulus types (monosyllables, words & sentences) was compared separately in 0dB, -5dB and -10dB SNRs. The results obtained for the original and envelope enhanced stimuli are reported separately.

Results of original stimuli: Figure 4.5 shows the median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained across the three stimuli types, in 0dB SNR, -5dB SNR and -10dB SNR, in individuals of control group, for the original stimuli.

The effect of stimulus type was found to be different across the three SNRs. In 0dB SNR, the median percentage of speech identification was same for all the three stimulus types. In -5dB SNR and -10dB SNR, the median identification was maximum for words. At -5dB SNR, the median identification of sentences was higher than monosyllables, whereas at -10dB SNR, the median identification for monosyllables was higher than sentences. The results of Friedman test showed a significant main effect of stimulus type in 0dB SNR [χ^2 (2) = 8.58, $p = 0.01$], -5dB SNR [χ^2 (2) = 18.94, $p < 0.01$], as well as -10dB SNR [χ^2 (2) = 28.13, $p < 0.01$] for the original stimuli. The pair-wise comparison using the Wilcoxon signed rank test showed that (Results shown in Figure 4.5) at 0dB SNR, significant difference was seen between words and monosyllables, and, words and sentences. There was no significant difference between sentences and monosyllables at 0dB SNR. A similar trend was seen at -5dB SNR. Whereas, there was a significant difference across all the three stimulus types in -10dB SNR.

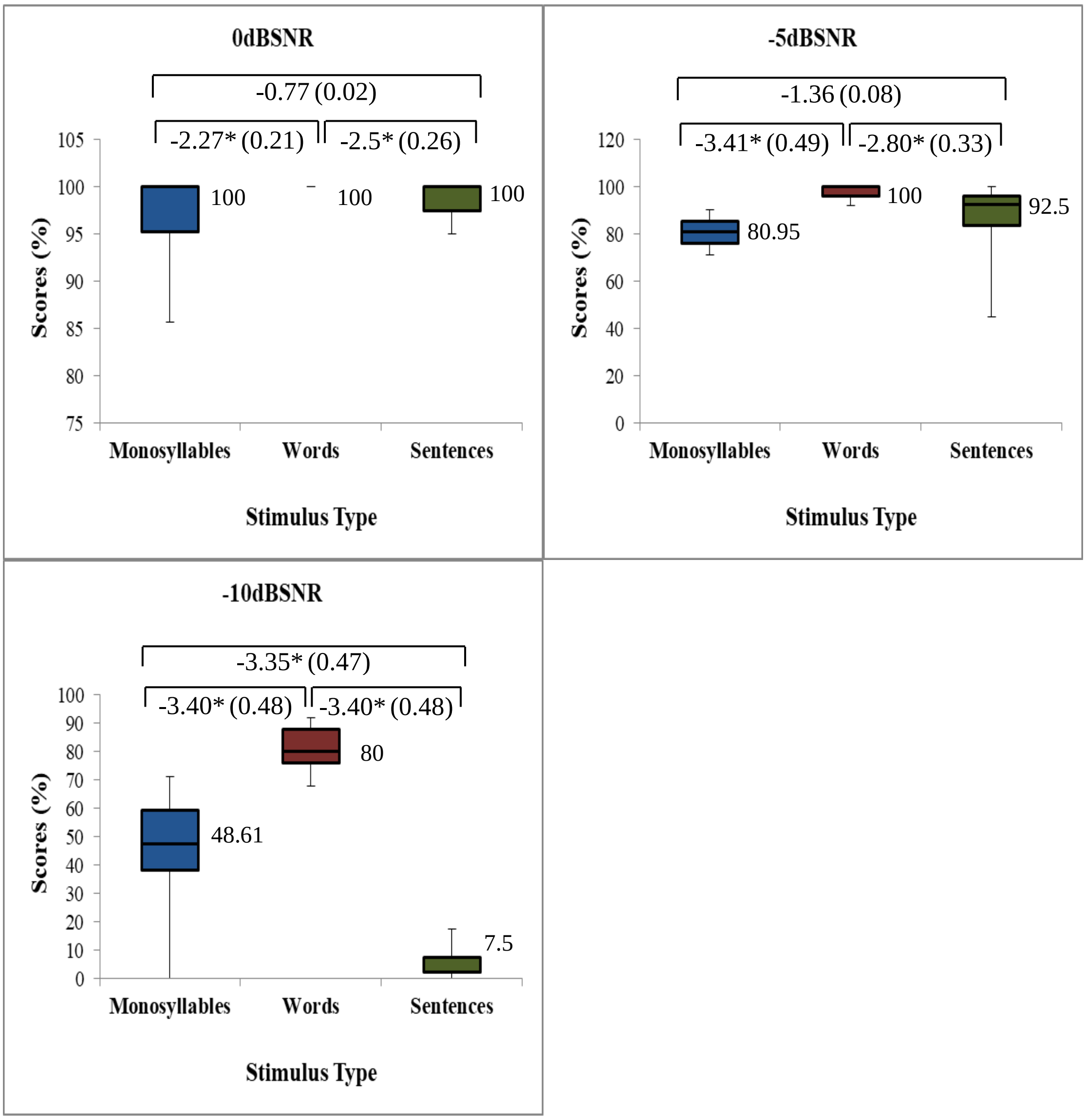

Figure 4.5: Median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained across the three stimulus types, at 0dB SNR, -5dB SNR and -10dB SNR, in control group, for the original stimuli. The error bars depict minimum and maximum scores. Wilcoxon Z and the effect size (in parentheses) are provided.

Note: * indicates significant difference ($p < 0.05$).

Results of envelope enhanced stimuli: Figure 4.6 shows the median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained across the three stimuli types, at 0dB, -5dB and -10dB SNRs, in individuals of control group, for the envelope enhanced stimuli.

At 0dB SNR, the median percentage of speech identification was same for words and sentences, and slightly higher than monosyllables. In -5dB SNR, the median identification was maximum for words, followed by sentences, and minimum for monosyllables. On the contrary, similar to the results of original stimuli, at -10dB SNR, the median percentage of speech identification in envelope enhanced stimuli was maximum for words, followed by monosyllables and minimum for sentences.

The results of Friedman test showed a significant main effect of stimulus type in -5dB SNR [$\chi^2 (2) = 26.13$, $p < 0.01$] and -10dB SNR [$\chi^2 (2) = 18.34$, $p < 0.01$], but not in 0dB SNR [$\chi^2 (2) = 5.31$, $p = 0.07$]. The subsequent pair-wise comparison (using the Wilcoxon signed rank test) showed that (Figure 4.6), for the data of -5dB SNR, there was a significant difference between words and monosyllables, and words and sentences. There was no significant difference between monosyllables and sentences in -5dB SNR. Whereas, in -10dB SNR, there was a significant difference across all the three types of stimuli.

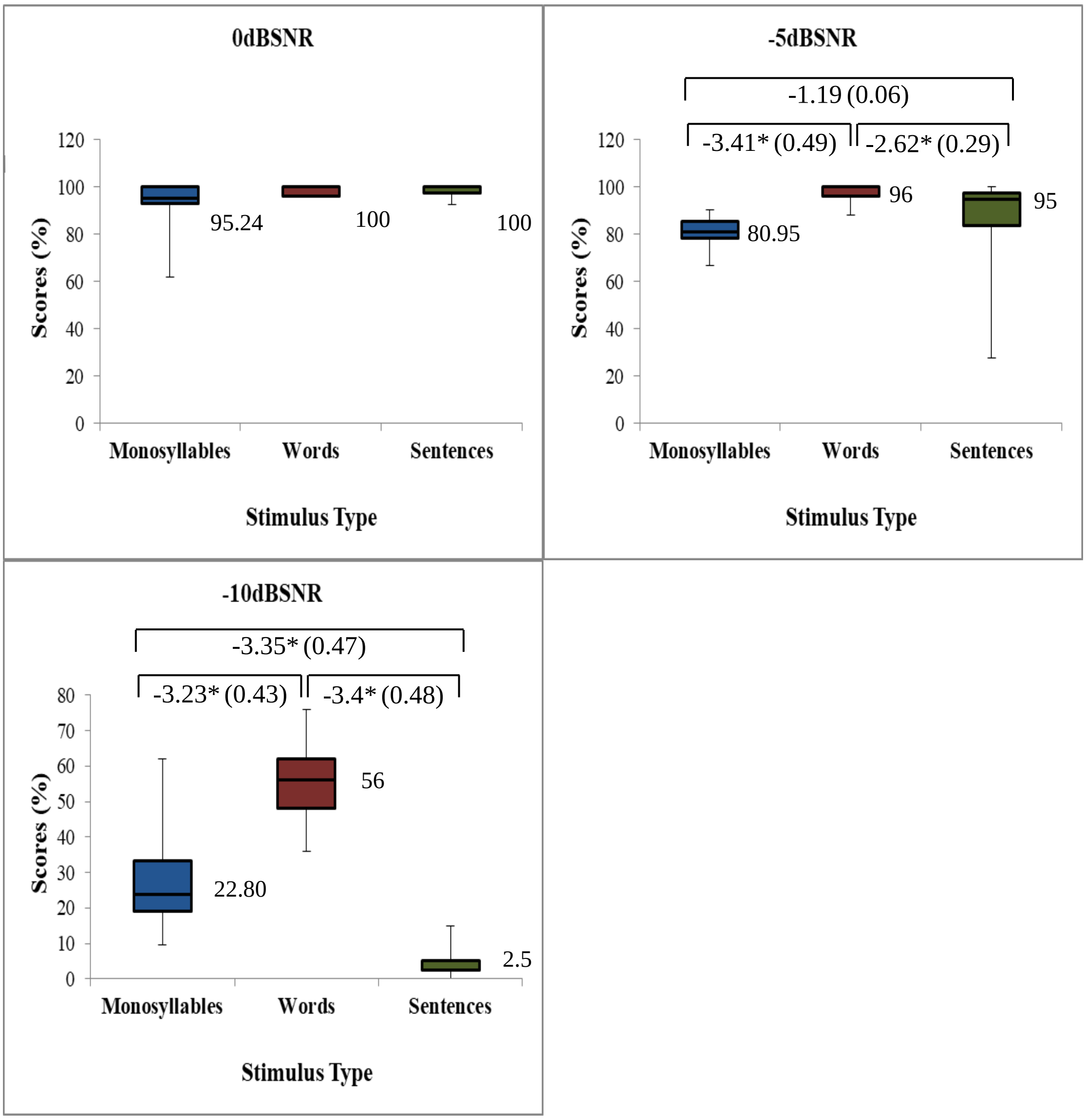

Figure 4.6: Median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained across the three stimulus types, in 0dB SNR, -5dB SNR and -10dB SNR, in individuals of control group, for the envelope enhanced stimuli. The error bars depict minimum and maximum scores. Wilcoxon Z and the effect size (in parentheses) are provided.

Note: * indicates significant difference ($p < 0.05$).

4.3 Effect of Group on Percentage of Speech Identification

The effect of group was assessed by comparing the percentage of speech identification between the two groups, separately in different stimulus conditions. Such comparison was meant to understand the benefits of envelope enhancement in individuals with ANSD relative to their control counterparts. The comparison was made for the percentage of speech identification obtained in the two groups at 0dB SNR, as this was the only SNR they were commonly tested with.

4.3.1 Result of original stimuli

Figure 4.7 shows the median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained in the two groups of participants for the original stimuli, in the three stimulus types, at 0dB SNR. It can be observed from the figure that the median percentage of identification of the control group were higher than that of ANSD group. This is true for all the three types of stimuli.

The percentage of speech identification obtained for original stimuli were compared between the two groups using Mann-Whitney U test. The results (Figure 4.7) indicated a significant difference between the two groups for all the three stimuli.

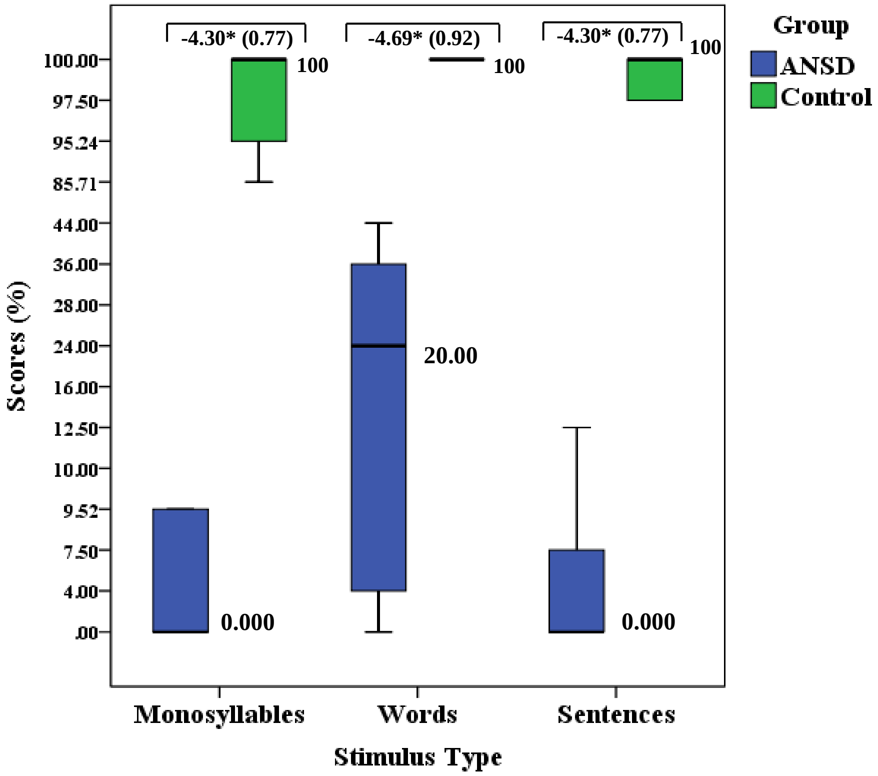

Figure 4.7: Median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained for original stimulus condition, for all three stimuli types, in 0dB SNR in the ANSD and control groups. The error bars depict minimum and maximum scores. Mann-Whitney Z and the effect size (in parentheses) are provided.

Note: * indicates significant difference ($p < 0.05$).

4.3.2. Result of envelope enhanced stimuli

Figure 4.8 shows the median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained in the two groups of participants for the envelope enhanced stimuli, in the three stimulus types, at 0dB SNR. Similar to that of original stimuli, the median percentage of identification of envelope enhanced stimuli was higher in the control group compared to ANSD group. This was true for all the three types of stimuli.

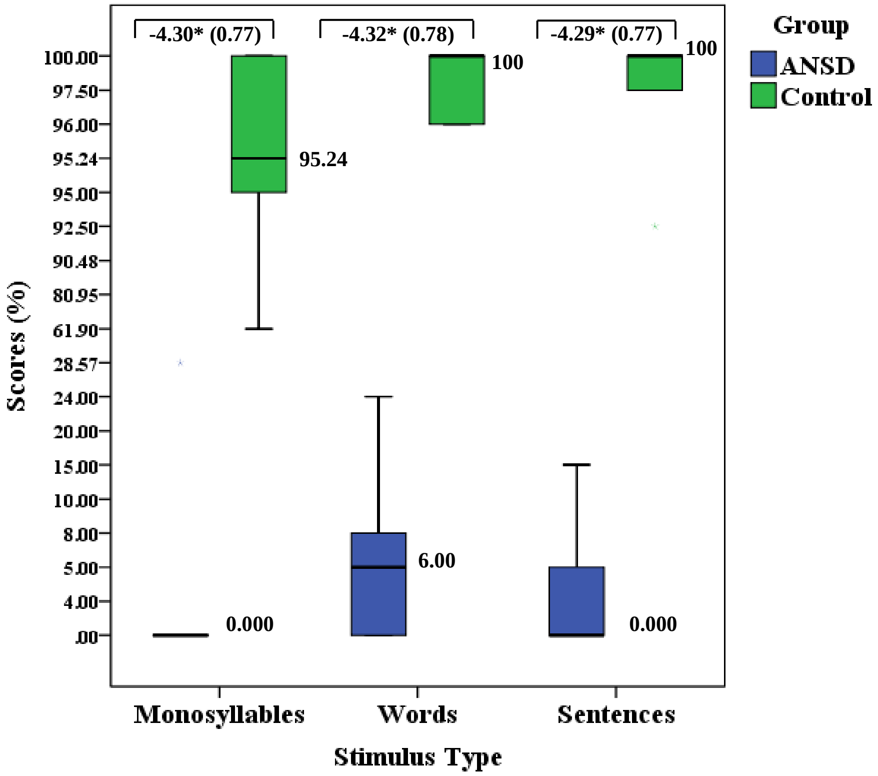

Figure 4.8: Median, inter-quartile range and range (minimum & maximum) of percentage of speech identification obtained for envelope enhanced stimuli, for all three stimuli types, at 0dB SNR in the ANSD and control groups. The error bars depict minimum and maximum scores. Mann Whitney Z and the effect size (in parentheses) are provided.

Note: * indicates significant difference ($p < 0.05$).

The results of Mann-Whitney U test (Figure 4.8) revealed a significant difference between the two groups for all the three stimuli; monosyllables ($Z = -4.30$, $p < 0.01$), words ($Z = -4.32$, $p < 0.01$) and sentences ($Z = -4.29$, $p < 0.01$).

4.3.3 Effect of group on Difference score of speech identification

In order to understand the relative benefit of envelope enhancement in the speech identification of the two groups of participants, the two groups were compared in terms of the 'Difference score'. The Difference score was calculated by subtracting the percentage of speech identification obtained for envelope enhanced stimuli from that of original stimuli. Figure 4.9 shows the median, inter-quartile range and range (minimum & maximum) of the Difference score obtained for the three stimulus types at 0dB SNR in the two groups participants.

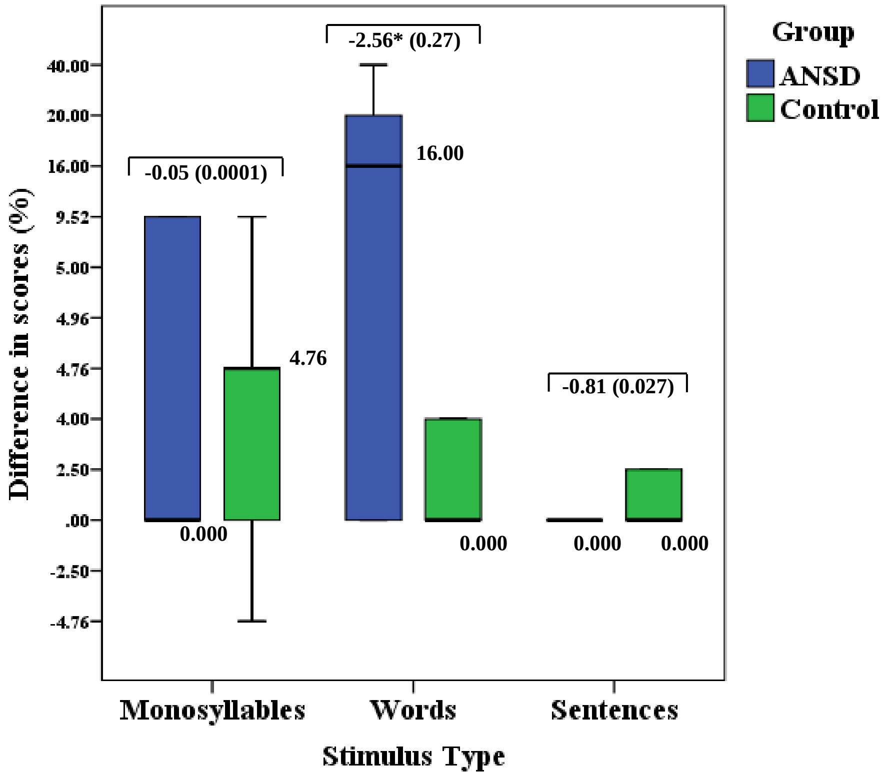

Figure 4.9: Median, inter-quartile range and range (minimum & maximum) of Difference score for the three stimulus types at 0dB SNR in the ANSD and control groups. The error bars depict minimum and maximum scores. Mann Whitney Z and the effect size (in parentheses) are provided.

Note: * indicates significant difference ($p < 0.05$).

From Figure 4.9, it can be observed that the median Difference score varied between the groups depending on the type of stimulus. In monosyllables, median was higher in ANSD group compared to control group while it was vice versa in words. The median scores did not change between the groups in sentences. The median Difference scores were statistically compared between the two groups using Mann-Whitney U test. The results (Figure 4.9) indicated a significant difference between the two groups for words, whereas there was no significant difference between the groups for monosyllables and sentences.

Chapter 5

DISCUSSION

The auditory management of individuals with ANSD is one of the most difficult conundrums for the audiologists. Several acoustic enhancement strategies have been studied in the past in an attempt to improve speech perception in individuals with ANSD. The existing literature suggests envelope enhancement strategy to be most beneficial in improving speech perception in these individuals. However, in spite of utilising exactly the same procedure for envelope enhancement, the extent of benefits reported is highly variable across different studies. A close look at the methods adopted in different studies showed that the stimuli utilized were different. Therefore, the present study attempted to assess the effect of stimuli on the perceptual benefit derived from envelope enhancement in individuals with ANSD. The results found are discussed in light of the existing literature, under the following headings;

1) Significance of envelope enhancement in improving speech perception of individuals with ANSD
2) Influence of stimulus type on the speech perception of individuals with ANSD
3) Influence of stimulus type on the perceptual benefit derived from envelope enhancement of speech in individuals with ANSD

5.1 Significance of Envelope Enhancement in Improving Speech Perception of Individuals with ANSD

Several psychophysical studies (Kumar & Jayaram, 2005; Rance, McKay, & Grayden, 2004; Zeng, Oba, Garde, Sininger, & Starr, 1999) had found that the limited speech perception in individuals with ANSD is due to their inability to follow amplitude variations in speech. Thus, it was speculated that envelope enhancement would enhance speech perception in these individuals. The findings of the present study revealed that envelope enhancement did not improve speech perception in quiet, in individuals with ANSD. This is true for all the three types of stimuli. The findings contradict with that of Narne and Vanaja (2009a, 2009b, & 2012) wherein significant improvement in speech perception were shown with the envelope enhancement of speech. But the current findings are in agreement with that of Balan and Maruthy (2018). It is important to note that the scheme of envelope enhancement used in all the studies was adopted from Apoux, Tribut, and Debruille (2004) and the sample figures shown in Figure 3.2 clearly show enhancement in the envelope of the stimuli used in the present study. Yet, no improvement in the speech perception was observed.

The effects of envelope enhancement depended on the specific stimuli used. While there was no significant difference with the envelope enhancement in monosyllables, the perception of words and sentences showed deterioration with envelope enhancement. This is a novel finding which suggests that envelope enhancement strategy is deleterious in individuals with ANSD. Support for this finding can be drawn from a close observation of the individual data of Balan (2018). The figure (Figure 4.13) shows that many of their participants with ANSD had poorer perception with envelope enhancement compared to the original stimuli. The exact reason for lack of benefit from envelope enhancement is not known. However, one can attribute it to the reduced naturalness of the stimuli secondary to envelope enhancement. In the scheme of envelope enhancement used, the original signal was passed through multiple band-pass filters and was subjected to full-wave rectification and low-pass filtering. As a consequence, there was inadvertent loss of naturalness observed in the envelope enhanced stimuli.

Another possible reason for the deterioration in perception of envelope enhanced stimuli is that it was a first-time experience for the participants, listening to the envelope enhanced stimuli. Considering the naturalness of the stimuli was affected, individuals with ANSD would have failed to appreciate the enhanced cues in their first time experience. However, with sufficient experience with such stimuli, they may develop the ability to utilise the envelope cues effectively. It is important to note that neither of the possible explanations (loss of naturalness & lack of experience with the envelope enhanced stimuli) justify the difference of the current findings with those of Narne and Vanaja (2009a, 2009b, & 2012).

As expected, the speech perception of individuals with ANSD drastically deteriorated at 0dB SNR. The percentage of identification reached zero in monosyllables and sentences for original as well as envelope enhanced stimuli. The results showed no significant difference in either of the stimulus types. This suggests that envelope enhancement did not facilitate speech perception even in the presence of noise. However when words were used, results showed that speech perception deteriorated with envelope enhancement compared to original stimuli. Therefore, it can be inferred that envelope enhancement is not useful for individuals with ANSD.

Such a phenomenon was not observable in monosyllables and sentences due to the floor effect.

Compared to the findings of Balan and Maruthy (2018), the current findings make unique contribution to the literature. The results of Balan and Maruthy (2018) were limited to the perception of stop consonants. Whereas, the present study utilized all the classes of consonants, despite which no improvement in perception of monosyllables was seen with envelope enhancement.

Neural synchrony at the level of eighth nerve as well as at the brainstem level plays a vital role in speech perception. In addition to the envelope cues, neural mechanisms which represent temporal fine-structure of a stimulus are critical for speech perception in noise (Kraus et al., 2000). Thus, in the current study, the control participants were tested in adverse listening conditions (0dB, -5dB, & -10dB SNRs) to see whether envelope enhancement of speech helps these individuals to extract the cues for speech perception in noise effectively.

The findings of the present study revealed that, irrespective of the stimulus type, envelope enhancement significantly worsened the perception of speech compared to the original stimuli at -10dB SNR. The findings clearly imply that although acoustically the enhancement in envelope is observed (Figure 3.2), the strategy failed to improve speech perception in challenging situations in individuals with normal auditory abilities. This can be a potential reason for the derogatory effects of envelope enhancement on the speech perception of individuals with ANSD. Such a phenomenon was not observed at 0dB and -5dB SNRs due to ceiling effect. These findings warrant modifications in the envelope enhancement schemes to improve speech perception in individuals with ANSD.

5.2 Influence of Stimulus Type on the Speech Perception of Individuals with ANSD

The findings of the present study indicate definite effects of stimulus type on the speech perception of individuals with ANSD. The words were found to be easier to perceive compared to sentences and monosyllables, irrespective of the stimulus condition, SNR, and group. Among monosyllables and sentences, the ease of perception appeared to depend on the group. While in individuals with ANSD, sentences were perceived better than monosyllables, in participants of control group, monosyllables were perceived better than the sentences (the trend seen at -10dB SNR).

The words being better than monosyllables partly justifies the contradictory results of Narne and Vanaja (2009a, 2009b, & 2012) and Balan and Maruthy (2018). Narne and Vanaja (2009a, 2009b, & 2012) had used words in their study, whereas Balan and Maruthy (2018) had utilised monosyllables. The difference in the ease of perception of the two types of stimuli could have influenced the difference in the results. The words being relatively more linguistically redundant than the monosyllables would have led to better ease of perception.

In the study, it was found that words were perceived better than even the sentences, despite sentences being linguistically richer compared to words. This was an unexpected finding which indicates that linguistic redundancy is not the only parameter that predominantly determines the speech perception in ANSD. In the perception of sentences, participants were expected to repeat four keywords in sentences of four-five words. This would have led to additional cognitive load which appeared to negatively influence the perception. The findings suggest that words or probably phrases result in maximum performance and this stimulus factor needs a serious consideration while deciding stimulus for testing speech perception in ANSD.

Furthermore, it was found that the sentences are perceived better than monosyllables in individuals with ANSD, particularly in the quiet condition. The finding can be attributed to the higher linguistic redundancy present in the sentences. The role of higher cognitive load speculated for the perception of sentences seem to have less influential role compared to linguistic redundancy. This is supported by the current results that the sentences are better than monosyllables but poorer than words in terms of their ease of perception.

Similar to individuals with ANSD, the participants of control group showed a clear influence of stimulus type on the ease of perception. This was evidently observed at lower SNRs (-5dB & -10dB). Even in participants of control group, the words were found to be easier compared to monosyllables and sentences. The difference between the monosyllables and sentences were evident only in very poor SNR (-10dB SNR). Words being better than monosyllables can be attributed to the higher linguistic redundancy present in words. On the contrary, sentences being poorer than words indicate that linguistic redundancy is not the only factor that plays role in speech perception. Considering that the task was to repeat most of the words in the sentences presented, it appears that there is increased cognitive load in the perception of sentences which has a negative influence on it.

At -10dB SNR, it was found that sentences resulted in perception poorer than monosyllables. This suggests that the cognitive load seen in the perception of sentences (particularly at lower SNRs) has a greater influence compared to the role of linguistic redundancy. The finding is contradictory compared to that seen in ANSD group. The comparison suggests that individuals with ANSD are able to make effective use of the available redundant cues, despite the negative influence of cognitive load. Whereas, individuals in the control group were not exposed to challenging listening conditions on a daily basis due to which they could not effectively counter the effects of cognitive load and make use of rich linguistic redundancy of sentences.

Overall, the findings support the influence of stimulus type on the speech perception of individuals with ANSD as well as those of the control group. Comparison across the three stimulus types in different stimulus conditions and in the two groups shows that linguistic redundancy is not the only parameter that determines speech perception. Cognitive load also plays a crucial role.

5.3 Influence of Stimulus Type on the Perceptual Benefit Derived from Envelope Enhancement of Speech in Individuals with ANSD

The findings of the present study showed that speech perception with envelope enhancement was significantly influenced by the stimulus type. The influence of stimulus type on the perceptual benefit derived from envelope enhancement was additionally derived in this study by taking the difference of percentage of speech identification obtained for original and envelope enhanced stimuli. The Difference scores were negligible in monosyllables and sentences in both the groups of participants. The Difference scores when compared between the two groups of participants showed that the benefit derived from envelope enhancement was comparable between the two groups in monosyllables and sentences. This implies that envelope enhancement is ineffective in enhancing perception of difficult stimuli such as monosyllables which are least redundant in nature. Additionally, envelope enhancement also fails to enhance perception of highly redundant stimuli such as sentences.

However, the Difference scores were significantly different between ANSD and the control groups in words. But it was found that the perception of words was deteriorated with envelope enhancement in individuals with ANSD, and in the participants of control group the Difference score was negligible. This is an unconventional finding which warrants the need to revisit the schemes of envelope enhancement. In support of this claim made based on the current findings, Moshgelani, Parsa, Allan, Veeranna, and Allen (2019) stated that schemes of envelope enhancement have to be different across monosyllables, words and sentences.

Chapter 6

SUMMARY AND CONCLUSIONS

In an attempt to improve speech perception in individuals with ANSD, several acoustic enhancement strategies have been studied in the past. The existing literature suggests envelope enhancement strategy to be most beneficial in improving speech perception in these individuals. However, in spite of utilising the exactly same procedure for envelope enhancement, the extent of benefits in speech perception is highly variable across different studies. A close look at the methods adopted in different studies showed that the stimuli utilized were different. Therefore, the present study aimed to investigate the effect of different type of stimuli on the perceptual benefit derived from envelope enhancement of speech in individuals with ANSD.

The study incorporated a quasi-experimental mixed group research design. There were two groups of participants in the age range of 14 to 36 years. The clinical group had 10 participants diagnosed to have ANSD, while the control group had 15 age-matched individuals with normal auditory abilities. The three types of stimuli used in the study were monosyllables, words, and sentences. Both ANSD and control groups were tested for their speech identification of original and envelope enhanced stimuli, in the three types of stimuli. The participants in the ANSD group were tested in two listening conditions, namely, in quiet and at 0dB SNR. Whereas, the participants in the control group were tested at 0dB, -5dB and -10dB SNRs. Subsequently, the raw scores obtained were converted into percentage, which in turn was subjected to further statistical analysis.

Based on the results of normality test, Friedman and Wilcoxon Sign Rank tests were used to study the effect of envelope enhancement (operationally defined as stimulus condition) and different stimulus type (monosyllables, words & sentences) on the percentage of speech identification. The effect of group was assessed using the Mann-Whitney U test.

The results revealed that the effects of envelope enhancement depended on the specific stimuli used. In most stimulus condition, there was no significant effect of envelope enhancement on speech perception. However, in some instances, a significant effect was observed. But instead of facilitation, the perception deteriorated with envelope enhancement of speech. Among the three stimulus types, words were found to be easiest to perceive compared to sentences and monosyllables irrespective of the stimulus condition, SNR, and group. Among monosyllables and sentences, the ease of perception appeared to depend on the group. While in individuals with ANSD, sentences were perceived better than monosyllables, it was vice versa in control group. This variation in performance was attributed to the differential role of linguistic redundancy and cognitive load on the perception of these stimuli.

The findings of the present study indicate deleterious influence of envelope enhancement on the speech perception of individuals with ANSD which are unconventional when compared to some of the previous studies. This warrants modifications in the envelope enhancement schemes to improve speech perception in these individuals. Also, the findings suggest unequivocal effects of stimulus type on the speech perception of individuals with ANSD, which should be taken into consideration while deciding stimulus for testing these individuals.

REFERENCES

American National Standards Institute. (1999). *American National Standard Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms*. ANSI S3.1- (1999). New York: American National Standards Institute.

ANSI. Specifications for Immittance, American National Standards Institute: New York, NY, S3.39-1987 (R1996).

Apoux, F., Tribut, N., Debruille, X.,et al. (2004). Identification of envelop expanded sentences in normal-hearing and hearing-impaired listeners. *Hearing Research, 189*, 13-24.

Barman, A. (2008). *Psycho acoustic profile in Normals and Individuals with Auditory Dys-Synchrony* (Unpublished doctoral thesis). University of Mysore, Mysore.

Balan, J. R. (2018). Effect of Acoustical Enhancement of Speech on Audio-visual Perception in Individuals with Auditory Neuropathy Spectrum Disorders (Unpublished doctoral thesis). University of Mysore, Mysore.

Balan, J. R., & Maruthy, S. (2018). The relative contribution of visual cues and acoustic enhancement strategies in improving speech perception of individuals with auditory neuropathy spectrum disorders. *Indian Journal of Otology*, *24*(3), 139.

Berger, K. W. (1969). Speech discrimination task using multiple-choice key words in sentences. *Journal of Auditory Research*, *9*(3), 247-262.

Bhattacharya, A., & Zeng, F. G. (2007). Companding to improve cochlear-implant speech recognition in speech-shaped noise. *The Journal of the Acoustical Society of America*, *122*(2), 1079-1089.

Carhart, R., & Jerger, J. F. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of speech and hearing disorders*, *24*(4), 330-345.

Carhart, R. (1965). Problems in the measurement of speech discrimination. *Archives of otolaryngology*, *82*(3), 253-260.

Davis, H., & Silverman, S. R. (1970). *Hearing and deafness*. Holt, Rinehart & Winston of Canada Ltd.

Egan, J. P. (1948). Articulation testing methods. *The Laryngoscope*, *58*(9), 955-991.

Epstein, A. (1978). Speech audiometry. *Otolaryngologic Clinics of North America*, *11*(3), 667-676.

Geetha, C., Kumar, K. S., Manjula, P., & Pavan, M. (2011). Development and standardisation of the sentence identification test in the Kannada language. Unpublished project funded by AIISH research fund submitted to AIISH, Mysore.

Giolas, T. G., & Epstein, A. (1963). Comparative intelligibility of word lists and continuous discourse. *Journal of Speech and Hearing Research*, *6*(4), 349-358.

Giolas, T. G., & Duffy, J.R. (1970). Comparison of sentence discrimination and conventional speech discrimination scores. *Journal of Speech and Hearing Research*, *13,755-767.*

Gnanateja, G. N., & Barman,A. (2011). *Relation between consonant perception and psychoacoustic measures in individuals with auditory dys-synchrony*. (Unpublished dissertation). University of Mysore, Mysore.

Hall, J. W. (2007). *New handbook of auditory evoked responses* (Vol. 1). Boston: Pearson.

Hassan, D. M. (2011). Perception of temporally modified speech in auditory neuropathy. *International journal of audiology*, *50*(1), 41-49.

Hirsh, I. J. (1952). The measurement of hearing. New York: Mcgraw-Hill Book Co.

Houtgast, T., & Steeneken, H. J. (1985). A review of the MTF concept in room acoustics and its use for estimating speech intelligibility in auditoria. *The Journal of the Acoustical Society of America*, *77*(3), 1069-1077.

Kraus, N., Bradlow, A.R., Cheatham, J., Cunningham, C.D., King, D.B., Koch, T.G., Nicol, T.J., McGee, L.K., Stein, L.K., & Wright, B.A. (2000). Consequences of neural asynchrony : A case of auditory neuropathy. *Journal of the Association for Research in Otolaryngology, 1 (1),* 33–45.

Kumar, U.A., & Jayaram, M. (2005). Auditory processing in individuals with auditory neuropathy, *Behavioral and Brain Functions*, 1-21.

Kumar, U. A., & Jayaram, M. (2011). Speech perception in individuals with auditory dys-synchrony, *The Journal of Laryngology and Otology, 125*, 236–245.

Kumar, U. A., & Jayaram, M. (2013). Speech perception in individuals with auditory dys-synchrony: effect of lengthening of voice onset time and burst duration of speech segments. *The Journal of Laryngology & Otology*, *127*(7), 656-665.

MacLeod, A., & Summerfield, Q. (1987). Quantifying the contribution of vision to speech perception in noise. *British Journal of Audiology, 21*, 131-141.

Maruthy. S., & Geetha, C. (2011). Audiovisual perception and processing in individuals with auditory dys-synchrony. Unpublished project funded by AIISH research fund submitted to AIISH, Mysore.

Miller, G. A., Heise, G. A., & Lichten, W. (1951). The intelligibility of speech as a function of the context of the test materials. *Journal of experimental psychology*, *41*(5), 329.

Miyamoto, R.T., Kirk, K.I., Renshaw, J. & Hussain, D. (1999). Cochlear implantation in auditory neuropathy. *Laryngoscope, 109,* 181– 185.

Moore, B. C. (2008). The role of temporal fine structure processing in pitch perception, masking, and speech perception for normal-hearing and hearing-impaired people. *Journal of the Association for Research in Otolaryngology*, *9*(4), 399-406.

Moshgelani, F., Parsa, V., Allan, C., Veeranna, S. A., & Allen, P. (2019). Objective and subjective assessment of envelope enhancement algorithms for assistive hearing devices. *Biomedical Signal Processing and Control*, *47*, 16-25.

Narne, V. K., Barman, A., Deepthi, M., & Shachi. (2014). Effect of companding on speech recognition in quiet and noise for listeners with ANSD. *International journal of audiology*, *53*(2), 94-100.

Narne, V. K., & Vanaja, C. S. (2008). Effect of envelope enhancement on speech perception in individuals with auditory neuropathy. *Ear and hearing*, *29*(1), 45-53.

Narne, V.K., & Vanaja, C.S. (2009a). Perception of envelope enhanced speech in the presence of noise by individuals with auditory neuropathy. *Ear and Hearing, 30(1)*, 136–142.

Narne, V. K., & Vanaja, C. S. (2009b). Perception of speech with envelope enhancement in individuals with auditory neuropathy and simulated loss of temporal modulation processing. *International journal of audiology*, *48*(10), 700-707.

Narne, V. K., & Vanaja, C. S. (2012). Speech Identification with Temporal and Spectral Modification in Subjects with Auditory Neuropathy. *ISRN otolaryngology*, *2012*.

Narne, V. K. (2008). *Perception of spectral and temporal modification of speech in individuals with auditory dys-synchrony* (Unpublished doctoral thesis). University of Mysore, Mysore.

Nittrouer, S., & Boothroyd, A. (1990). Context effects in phoneme and word recognition by young children and older adults. *The Journal of the Acoustical Society of America*, *87*(6), 2705-2715.

Pottackal Mathai, J., & Yathiraj, A. (2013). Effect of temporal modification and vowel context on speech perception in individuals with auditory neuropathy spectrum disorder (ANSD). *Hearing, Balance and Communication*, *11*(4), 198-207.

Prabhu, P., Avilala, V., & Barman, A. (2011). Speech perception abilities for spectrally modified signals in individuals with auditory dys-synchrony. *International journal of audiology, 50*(5), 349-352.

Rance, G. (2005). Auditory neuropathy/dys-synchrony and its perceptual consequences. *Trends in Amplification*, *9*(1), 1-43.

Rance, G., Barker, E., Mok, M., Dowell, R., Rincon, A., & Garratt, R. (2007). Speech perception in noise for children with auditory neuropathy/dys-synchrony type hearing loss. *Ear and Hearing*, *28*, 351–360.

Rance, G., & Barker, E. J. (2008). Speech perception in children with auditory neuropathy/dyssynchrony managed with either hearing aids or cochlear implants. *Otology & Neurotology*, *29*(2), 179-182.

Rance, G., Corben, L. A., Du Bourg, E., King, A., & Delatycki, M. B. (2010). Successful treatment of auditory perceptual disorder in individuals with Friedreich ataxia. *Neuroscience*, *171*(2), 552-555.

Rance, G., McKay, C., & Grayden, D. (2004). Perceptual characterization of children with auditory neuropathy. *Ear and Hearing* 25: 34–46

Shallop, J., Peterson, A., Facer, G., Fabry, L., & Discoll, C. (2001).Cochlear implants in five cases of auditory neuropathy: Postoperative findings and progress. *Laryngoscope*, *111*, 555-562. 40

Shallop, J.K. (2002). Auditory neuropathy/dys-synchrony in adults and children. *Seminars in Hearing*, 23 (3), 215–223.

Silverman, S. R., & Hirsh, I. J. (1955). Problems Related to the Use of Speech in Clinical Audiometry. *Annals of Otology, Rhinology & Laryngology*, *64*(4), 1234-1244.

Starr, A., McPherson, D., Patterson, J., Don, M., Luxford, W., Shannon, R, Sininger, Y., Tonakawa, L., et al. (1991). Absence of both auditory evoked potential and auditory percepts dependent on timing cues. *Brain*, *114*, 1157-1180.

Starr, A., Picton, T. W., Sininger, Y., Hood, L. J., & Berlin, C. I. (1996). Auditory neuropathy. *Brain*, *119*(3), 741-753.

Starr, A., Sininger, Y.S., & Pratt, H. (2000). The varieties of auditory neuropathy. *Journal of Basic ClinicalPhysiology and Pharmacology, 11(3)*,215–230

Turicchia, L., & Sarpeshkar, R. (2005). A Bio-Inspired Companding Strategy for Spectral Enhancement. IEEE Transactions On Speech And Audio Processing, *13*(2), 243-253.

Tye-Murray, N., Sommers, M. S., & Spehar, B. (2007). Audiovisual integration and lip-reading abilities of older adults with normal and impaired hearing. *Ear and Hearing*, *28(5)*, 656-668.

Tyler, R. S., Fernandes, M., & Wood, E. J. (1980). Masking, temporal integration and speech intelligibility in individuals with noise-induced hearing loss. In *Disorders of auditory function*(pp. 211-236).

Venkatesan, S. (2009). Ethical guidelines for bio behavioral research involving human subject. All India Institute of Speech and Hearing. Mysuru. doi:10.1017/CBO9781107415324.004

Yathiraj A. & Vijayalakshmi C.S. 2006. Auditory memory test. A test developed at the Department of Audiology, AIISH, Mysore.

Zeng, F.G., Kong, Y.Y., Michalewski, H.J., & Starr, A. (2005). Perceptual consequences of disrupted auditory nerve activity. *Journal of Neurophysiology 93,* 3050–3063

Zeng, F. G., & Liu, S. (2006). Speech Perception in Individuals with Auditory Neuropathy. *Journal of Speech, Language, and Hearing Research, (49),* 367–380.

Zeng, F.G., Oba, S., Garde, S., Sininger, Y., & Starr, A. (1999). Temporal and speech processing deficits in auditory neuropathy. *NeuroReport*, *10,* 3429- 3435.

Züst, H. J., & Tschopp, K. (1995). The context effect in speech recognition of sentences. *Laryngo-rhino-otologie*, *74*(6), 375-379.

APPENDIX 1

Demographic details and audiological profile of participants in the ANSD group

SL. No.	Age (years)	Sex	Pure tone average of better ear (dBHL)	Speech Identification Scores (%)
1	17	F	13.75	40
2	15	M	12.4	48
3	25	M	30	60
4	19	F	45	60
5	25	F	36.25	52
6	22	F	8.75	64
7	23	F	55.25	56
8	32	F	15	60
9	36	F	20	64
10	14	F	35	35

APPENDIX 2

Results of Shapiro-Wilk test of normality for the measures of ANSD group (df = 10) and Control group (df = 15)

ANSD Group			
Stimulus Condition	SNR	Stimulus Type	p
Original	Quiet	Monosyllables	0.27
Original	Quiet	Words	0.97
Original	Quiet	Sentences	0.51
Envelope enhanced	Quiet	Monosyllables	0.049
Envelope enhanced	Quiet	Words	0.82
Envelope enhanced	Quiet	Sentences	0.037
Original	0dB SNR	Monosyllables	0.000
Original	0dB SNR	Words	0.39
Original	0dB SNR	Sentences	0.000
Envelope enhanced	0dB SNR	Monosyllables	0.000
Envelope enhanced	0dB SNR	Words	0.019
Envelope enhanced	0dB SNR	Sentences	0.000

Control Group			
Stimulus Condition	SNR	Stimulus Type	p
Original	0dB SNR	Monosyllables	0.000
Original	0dB SNR	Words	0.000
Original	0dB SNR	Sentences	0.001
Envelope enhanced	0dB SNR	Monosyllables	0.000
Envelope enhanced	0dB SNR	Words	0.000
Envelope enhanced	0dB SNR	Sentences	0.001
Original	-5dB SNR	Monosyllables	0.15
Original	-5dB SNR	Words	0.000
Original	-5dB SNR	Sentences	0.001
Envelope enhanced	-5dB SNR	Monosyllables	0.040
Envelope enhanced	-5dB SNR	Words	0.004
Envelope enhanced	-5dB SNR	Sentences	0.000
Original	-10dB SNR	Monosyllables	0.17
Original	-10dB SNR	Words	0.44
Original	-10dB SNR	Sentences	0.021
Envelope enhanced	-10dB SNR	Monosyllables	0.070
Envelope enhanced	-10dB SNR	Words	0.77
Envelope enhanced	-10dB SNR	Sentences	0.006